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MANUAL FOR ESTABLISHING VEGETATION ON LANDFILLS IN ONTARIO

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MANUAL FOR ESTABLISHING VEGETATION ON LANDFILLS IN ONTARIO

R. A. C. PROJECT NO. 307C

Prepared for Environment Ontario by:

Gartner Lee Limited
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1.0 INTRODUCTION

1.1 PURPOSE OF MANUAL

In 1987, 24 landfill sites throughout Ontario were examined. Of these, all of the open sites and 83% of the closed sites suffered from erosion problems. Not only does this cause aesthetic and operational concerns, but it fails to meet the requirements established by the Ontario Ministry of Environment (MOE), as specified in the "Certificate of Approval".

The purpose of this manual is twofold: to assist the landfill owner/operator with the remediation of erosion on landfill sites through establishment and management of vegetation; and to assist landfill designers with the prevention of erosion with a successful revegetation program.

Background

The cap of soil placed on the landfill and particularly on the side slopes is prone to erosion, both while the landfill is operating and after closure. A landfill cap isolates the waste materials from surface exposure. Therefore, it is desirable to maintain an erosion proof cap over all waste areas.

Erosion results not only in the loss of soil, but also in potential damage to the surface cap covering the refuse. That damage can lead to several problems:

- Garbage will be exposed, resulting in an attraction for nuisance animals such as rats and gulls.
- The appearance of the eroding slopes may be aesthetically unacceptable.
- The repair of the damaged cap will result in increased operating and maintenance costs.
- Opportunities for the emergence of landfill gases and leachate may be increased.

- On landfills designed to resist infiltration, a damaged cap may allow increased infiltration of rain water which will accelerate the production of leachate.

Typically, the cap materials are fine textured and highly compacted. On the landfill slopes, these soil characteristics offer a difficult environment for the establishment of vegetation. Site conditions further deteriorate on areas without an adequate vegetative cover. Water erosion, drought, and wind erosion on these sites make vegetation establishment and maintenance more costly and more difficult.

1.2 DIRECTIONS FOR USE

1.2.1 Manual Outline

A brief description of each section is provided:

- Section 2.0 provides background information on landfills in an Ontario context.

- Section 3.0 describes two procedures to be undertaken as part of an examination and inventory of the site. These procedures provide the information necessary to plan the required remediation. Reviewing Sections 3.0 and 4.0 is recommended before undertaking the on-site examination.

- Section 4.0 examines erosion related problems common on Ontario landfills. The nature of the problem is described, followed by key points of recognition on-site. Procedures to mitigate or correct the problem are described.

- Section 5.0 is devoted to planning a revegetation program, first identifying the characteristics to look for in choosing the species for the vegetative cover. Following are soil amendment techniques for consideration in seed bed preparation, and seeding methods.

- Section 6.0 runs through the entire process from planning to scheduling the work leading to seeding.

- Section 7.0 describes the need for a follow-up or monitoring program to ensure that the vegetation work is successful. A maintenance program is outlined. As well, keeping accurate and detailed records is recommended.

- Section 8.0 is a summary of the Manual and outlines the material provided in the Appendices.

- Section 9.0 acknowledges the assistance provided to assemble the Manual.

- Section 10.0 identifies the information cited numerically in the text of the Manual.

1.2.2 Application to Existing Operations

For existing landfill sites, Sections 3.0 to 7.0 will assist the operator in problem identification, analysis of potential remediation, implementation, and follow-up procedures. Opportunities to acquire additional information or assistance are provided throughout the text and in the references.

1.2.3 Use as a Planning Aid

When used as a planning aid for a new landfill site, Section 4.0 describes not only typical problems found on Ontario landfills, but also provides a characterization of the ideal circumstances which would avoid the problem altogether.

Sections 5.0 to 7.0 provide an outline of issues to be considered in designing a landfill. A well designed landfill may avoid many of the usual limitations found on existing sites which have always proven to be expensive and difficult to remediate and maintain.

The references (Section 10.0) and appendices provide additional and more detailed information.

2.0 LANDFILLS IN ONTARIO - BACKGROUND

2.1 GENERAL

Form

Landfills typically take one of three general forms in Ontario:

i) a hill or mound,
ii) a filled valley wall, or
iii) an excavated trench, backfilled with waste (Figure 1).

The mound may have originated in depressions or excavations such as abandoned pits or quarries. Both the mound and valley filling operations can result in steep sideslopes. The backfilled trench generally results in a flat, final grade. Owned by either public or private operators, landfills vary in size from less than a hectare to over 50 ha. The larger sites tend to be those that are closer to major urban areas.

Use

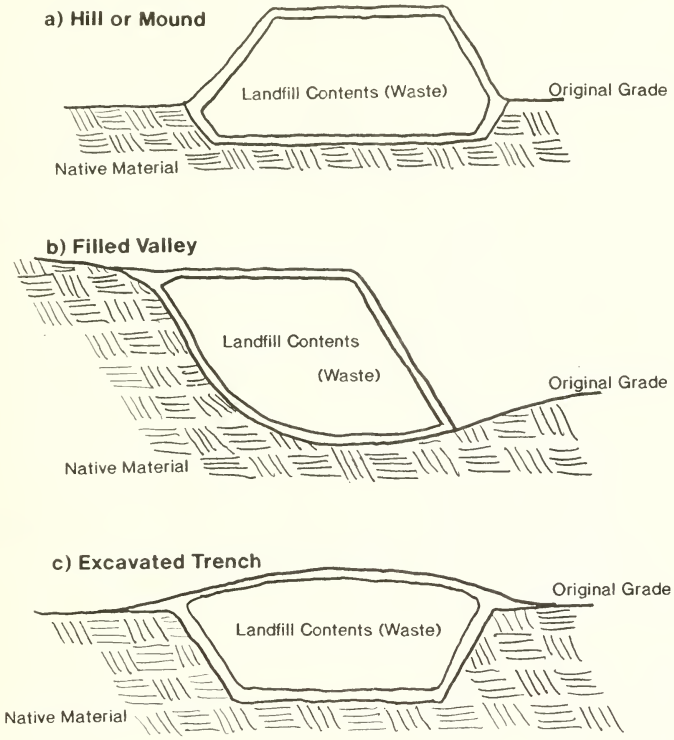
Landfills are used in Ontario for the disposal of waste materials. Sites can accept wastes from municipal, commercial and industrial sources, as specified in their Certificate of Approval. Many which pre-date current regulations, are closed or abandoned, and records for some are incomplete.

Structure

Landfills may or may not have a low permeability liner (compacted clay or synthetic material), on which the waste is deposited in layers or cells. A daily soil cover is required on all waste throughout the operation. When the site is closed it is topped with a dense cap material, generally about 0.5 m of compacted fine grained material. A layer of topsoil, where available, is spread on top to enhance growing conditions (Figure 2).

2.2 EXISTING STAGE OF SITE DEVELOPMENT

Landfill sites which are closed, or partially closed, generally offer few opportunities to significantly improve the physical conditions which cause or contribute to erosion problems (i.e., the structure, contents, cover, soil, and slopes are already present). The

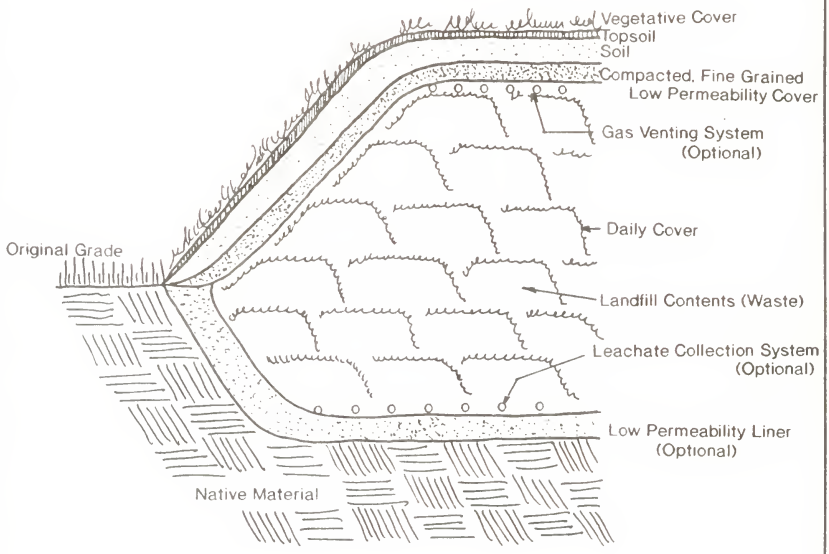


Legend

Generalized Landfill Forms (Cross Sections)

FIGURE 1

LANDFILL REVEGETATION MANUAL



Legend

Generalized Landfill Structure (Cross Section)

FIGURE 2

LANDFILL REVEGETATION MANUAL

reaction to erosion problems has to concentrate on quick repair and stabilization of the cap covering the refuse.

Landfill sites which are still open are operating under a Certificate of Approval which may or may not specify ideal sideslopes, gas and leachate collection, cap and cover details, and end use. The physical conditions which will cause or contribute to erosion problems should be examined and remediated, providing the conditions of the Certificate of Approval are not violated. Significant changes in the operating plan must be discussed with the MOE. Landfill sites in the planning stage should be designed to incorporate the best available technology with regard to the structure, the nature and placement of refuse, the angle of the sideslopes, the cap and cover, the end use, the establishment of vegetation, and the management of toxic by-products.

2.3 LANDFILL CONTENTS

The byproducts of decomposition are determined by the nature of the disposed refuse, as well as the physical characteristics of the landfill site. The gases and leachate from decomposing refuse can be a limiting factor in the establishment of vegetation or can cause "die-back" of existing vegetation, thus contributing to the onset of erosion.

Typical municipal household refuse contains large quantities of organic materials, high in water content. These break down quickly, releasing gases such as carbon dioxide, methane, and hydrogen sulfide, and a liquid leachate. Refuse from commercial and industrial sources may vary widely. It may include heavy metals, organic solvents, reactive chemicals, and/or inert materials. The decomposition byproducts from these materials can be much more toxic and/or diverse in nature.

Settlement is another problem related to the nature of the refuse, as well as to compaction and placement techniques. Bulky items, such as automobile bodies, refrigerators, tree stumps, etc. can collapse while decomposing. This leads to settlement of all materials above, including the cap. Settlement of the cap in isolated pockets can lead to increased infiltration of water, which may be undesirable on landfills designed to resist infiltration. This can result in higher gas and leachate production.

2.4 EXISTING VEGETATION

On landfill sites that are fully, or partially closed, an attempt may have been made to revegetate with or without a detailed plan, or the site may have naturally revegetated.

A topsoil cover on the low permeability cap material will facilitate the establishment of vegetation. However, topsoil is often not installed. In this case, the establishment of a vegetative cover must occur on the cap material. Because cap material is usually heavy textured and compacted, it makes a poor medium for vegetation establishment. Therefore, if an acceptable vegetative cover has become established, the successful species should be considered for use in repairing similar habitats elsewhere on the landfill.

If the cover is patchy or weedy, improvements can be made to assist acceptable species to develop. The existence of areas of dead or declining vegetation could indicate gas or leachate emissions, which can be short or long-term problems, and must be solved prior to successful revegetation.

2.5 ENGINEERED SYSTEMS

Increasingly, landfills are being outfitted and or retrofitted with engineered systems intended to control byproduct emissions. Landfill sites with gas collection and/or venting systems should have fewer problems related to vegetation die-back, since these systems should reduce the migration of landfill gases into the rooting zones of the vegetation.

However, the presence of gas collection and leachate collection/recirculation systems does not guarantee these byproducts will not interfere with vegetation establishment and management. Persistent problems may be related to the vertical impermeability of flattened plastic garbage bags and daily cover.

2.6 PROPOSED END USE

For existing landfills, the end use may be described in the Certificate of Approval, issued by the MOE. No other, or additional, use can be made of the site except with

the approval of the Minister of Environment (R.S.O. 1980, Chapter 141, section 45). Not all landfill sites have a proposed end use. Many sites are to be integrated into the local landscape with the planting of grass, trees, and shrubs.

A landfill may be designed to support or complement an end use, often related to recreation (golf, riding trails, model airplane flying, tennis, playing fields, etc.) but other possibilities exist.

Any proposed end use of the landfill should take into account the sensitivity of the vegetation and cover to disturbance, surface compaction, and potential erosion. Activities which require high turf maintenance regimes are not appropriate for a landfill cover and should not be allowed. Landfill slopes are particularly sensitive. Even a passive activity like a hiking trail can result in erosion.

2.7 CONTRADICTORY OBJECTIVES: PROMOTING RUNOFF OR PROMOTING VEGETATION

A landfill cap is usually intended to resist infiltration of precipitation. This is often achieved by installing a sloped, highly compacted layer of fine grained material, resulting in a cap of low permeability and high runoff. However, a cap of this nature is threatened by wind and water erosion, frost damage, and cracking from desiccation. In order to stabilize and protect the low permeability cap, it may be necessary to install a vegetative cover where little or no topsoil exists . However, the establishment of vegetation requires conditions which may contradict the original cap objectives of shedding water and resisting infiltration. As well, the low permeability cap may still be damaged and rendered permeable by frost action and desiccation, even if vegetation could be established on the cap. This further facilitates water infiltration into the waste, emission of gas and leachate, and erosion.

Improved Cap Design

An investigation of multi-layered, final cover systems (23) suggests that placement of an additional layer of uncompacted soil between the compacted low permeability cap and the topsoil would provide greater rooting depth, increased soil moisture storage, and protection of the compacted layer from frost and desiccation damage. To make this

viable, it is imperative that the compacted low permeability layer is adequately dense. This requires the use of kneading or punching equipment (i.e., sheepsfoot rollers) to place and compact the clay. As well, it is necessary that the compacted clay layer be covered with a sufficient depth of soil and topsoil to ensure that it is located completely below the average depth of frost penetration.

The benefits are:

- Easier establishment of vegetation due to the deeper rooting zone, greater soil moisture storage, and less stress from landfill gases and leachate.
- Greater choice of plant species since growing conditions are more favourable.
- Healthier vegetation, which in turn increases the evapotranspirative losses of precipitation, thus reducing infiltration.
- Presence of vegetation reduces frost penetration and prevents desiccation of the clay layer, thereby preserving its low permeability, which in turn reduces infiltration, and gas and leachate emissions.

This system could provide long-term cost effective benefits through reduced repair and maintenance costs (23).

3.0 REVIEW OF EXISTING CONDITIONS

In order to resolve erosion problems and establish or repair a vegetative cover, the problems need to be accurately assessed. This requires a thorough examination of the site which can provide valuable supplementary information to assist in planning the remediation.

Two systems have been prepared to help the operator gather and record information required to address the problem. The first is a check sheet of features to record the physical characteristics of the landfill for later analysis. The check sheet is to be completed on-site. The second system is a key, which presents 'either-or' descriptions of existing vegetation. The key provides a decision path for the operator to follow through to problem headings which are addressed in the text.

3.1 PROBLEM EVALUATION CHECK SHEET

The check sheet (Figures 3, 4 and 5) is intended to be used for examining problems related to the growth of vegetation on a slope. It can be completed in the field during regular site inspection tours and for special problem solving investigations.

Getting Ready

Familiarize yourself with the check sheet (Figure 3) and Sections 3.0 and 4.0 of the Manual before going out on site.

Equip yourself for a thorough examination of the entire landfill site by bringing along:

- copies of the site plan
- Ontario Base Map
- note pad
- soil sampling sheets
- air photos
- camera
- pencils
- clean shovel
- blank copies of this Check Sheet to be filled in as you go
- an assistant is helpful for note taking and as a measuring stick for determining slopes.
- safety boots, clothing, and equipment, as necessary.

FIGURE 3: PROBLEM EVALUATION CHECK SHEET

1. Instructions for Use

Locate the problem areas on the landfill and sketch them on a copy of the site plan, an air photo, or on the attached diagram (Fig. 4). Using a check sheet for each problem area, check off the details that apply. Identify the different problem areas on the map as A, B, C, etc. and use the same coding on the check sheet.

2. SITE: _____ DATE: _____
INSPECTOR: _____ WEATHER: _____

3. Pace the distance from the toe to the top of slope, across the problem area. Take big steps, considering that each pace is 1± metre. More details can be found in Section 4.1.

SLOPE LENGTH
Long (150 to 300m) _____
Medium (60 to 150m) _____
Short (30 to 60m) _____
Very Short (0 to 30m) _____

Check off correct range.

4. Have an assistant stand on the slope or use a stick about 2m in length which can be stuck into the ground. From a view point about 20 metres away on the same level, estimate the distance from the top of your assistant's head horizontally to the slope, using their height as a unit of measurement. This will give you the Vertical to Horizontal ratio of the slope, ie. one unit of height vertically = two units of height horizontally. Fig 5 shows other ways to measure slope steepness.

SLOPE STEEPNESS

Check off closest range

Vertical	:	Horizontal	
1	:	1 or Steeper	_____
1	:	2	_____
1	:	3	_____
1	:	4 or flatter	_____

5. On bare ground portions of the slope, look for:

° Upper layer of soil has washed away leaving exposed stones, sticks, debris

EROSION TYPES

SHEET EROSION:
Whole site* _____
Limited area* _____
Absent _____

Surface runoff has cut small channels (1 to 10 cm) in the cover materials

RILL EROSION:
Whole site* _____
Limited area* _____
Absent _____

Running water has cut one or more channels deeper than 10cm.

GULLY EROSION:
Present* _____
Absent _____

*Be sure to sketch on plan.

One, two, or three erosion types may be present on the same problem area. Refer to Section 4.2 for more details.

Check presence or absence of one or more erosion types, and note details such as length, width and depth.

FIGURE 3: (Cont'd).

6.	Using the soil texture field tests described in Appendix C of the manual, determine the soil texture, or collect small samples in plastic lunch bags and bring them back to analyse when you can refer to the test instructions. Remember to identify where the sample was taken, using the coding for the problem areas. Refer to Section 4.3.3 for further details.	SOIL TEXTURE Sand _____ Silt _____ Clay _____ Loam (topsoil) _____ Check or describe appropriate texture
7.	Look for dark soil colour with small bits of decaying leaves and roots. A small sample can be collected and labelled. When you get back, shake up the sample in a jar full of water. If there is organic matter in the sample, it will tend to float on the water in the jar. See also Section 4.3.4.	ORGANIC MATTER Present _____ Absent _____ Not Determined _____ Check presence or absence
8.	Observe whether the surface is smooth, hard, and/or difficult to push a shovel or stick into. This is further described in Section 4.3.1.	COMPACTION Yes (hard) _____ No (softer) _____ Not Determined _____
9.	The presence of cracks,or soil blowing into drifts, usually indicates dry conditions. Refer to section 4.3.6. for description.	LOW SOIL MOISTURE Yes _____ No _____ Not Determined _____

Inspector _____ Date _____

Weather _____

REFER TO FIGURE 3 SECTION 1. FOR COMPLETION INSTRUCTIONS

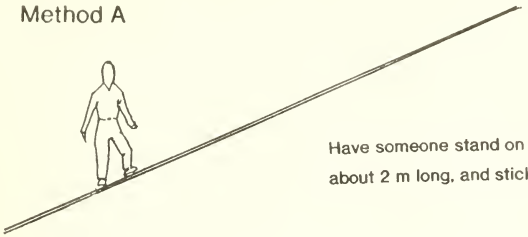
Add any other features : Property Lines . Fences . Water Courses . Treed Areas . Active Fill Areas . Access Points

Sketch Plan For Problem Areas

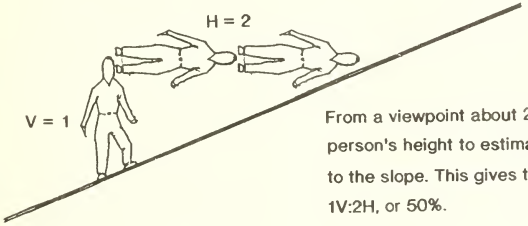
FIGURE 4

LANDFILL REVEGETATION MANUAL

Method A

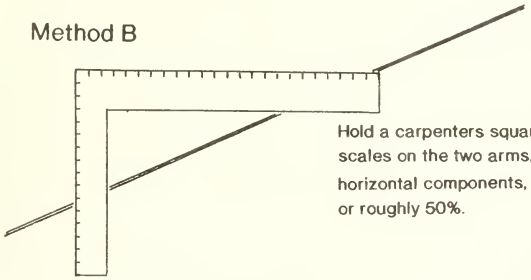


Have someone stand on the slope. Or, use a stick about 2 m long, and stick it into the ground.



From a viewpoint about 20 metres away, use the person's height to estimate the horizontal distance to the slope. This gives the V:H ratio, in this case 1V:2H, or 50%.

Method B



Hold a carpenters square at arm's length. Using the scales on the two arms, estimate the vertical and horizontal components, in this case about 11V:23H, or roughly 50%.

Legend	Measuring Slope Steepness	FIGURE 5
	LANDFILL REVEGETATION MANUAL	

3.2 KEY TO PROBLEM IDENTIFICATION

The key (Figure 6) is intended to be used in the field as an aid for identifying problems related to the growth of vegetation on a landfill.

Instructions for Use

Before going out on site, familiarize yourself with the Key and Section 4.0 of the Manual. Make copies of the Key to be completed on site. Then, for each 'problem area' on the landfill, proceed along the decision path. Since more than one factor may be contributing to the lack of vegetation, the key should be used as many times as necessary to determine all possibilities. As a permanent record, the decision path can be drawn in pen, or the decisions checked off, leading to the final step.

4.0 PROBLEMS AND SOLUTIONS

Although the causes of erosion-related problems on a landfill site are often interrelated, this section will examine them individually, first describing the problem and how to recognize it, then outlining how to overcome it.

4.1 SLOPE LENGTH AND STEEPNESS

Description of Problem:

- Slope length and slope angle are the most important factors in determining the susceptibility of a slope to erosion by rain and water.

- The two factors work in conjunction with each other, and as a general rule, the steeper and/or longer the slope, the greater the potential for runoff-related erosion.

- Slope steepness is of greater consequence than slope length in determining susceptibility to erosion; excessive steepness can also result in slippage and/or slope failure in which the internal structure of the soil is overcome by gravitational and hydraulic forces, causing the slope to collapse.

Recognition:

- Slope length is defined as the distance from the toe to the top of the slope (Figure 7). Slope length is expressed in metres.

KEY TO PROBLEM IDENTIFICATION

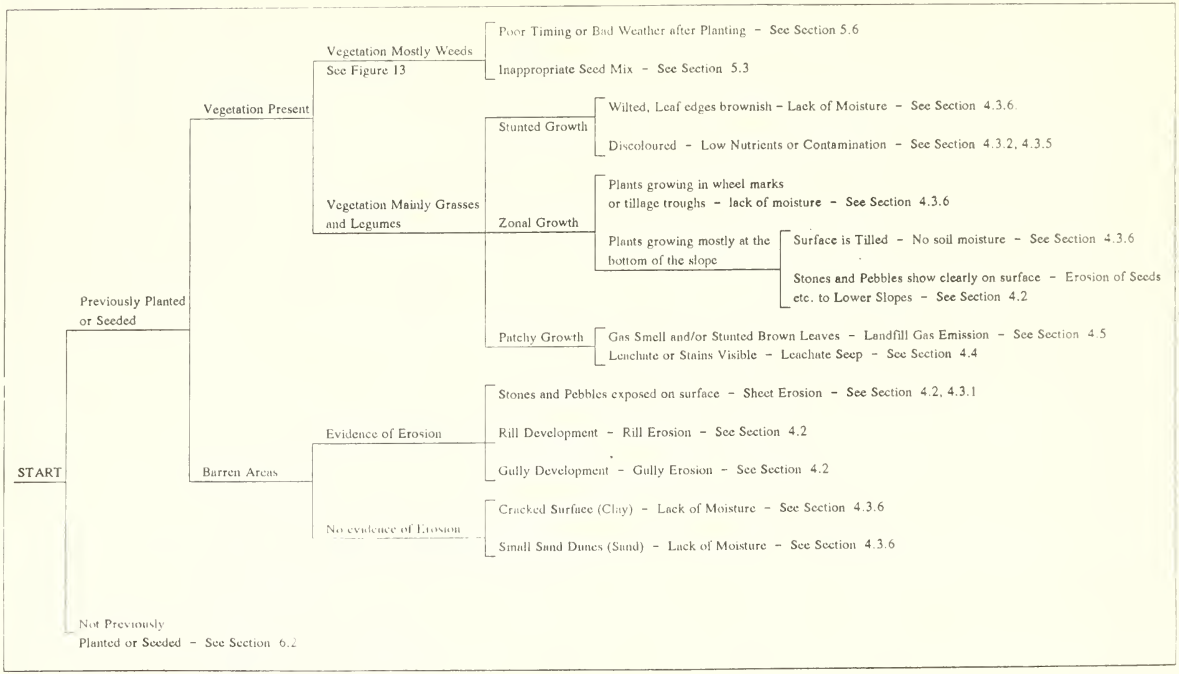
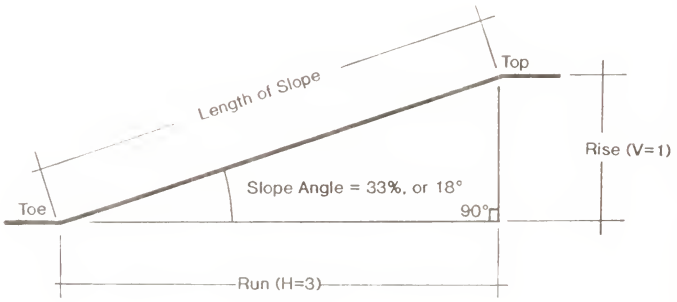
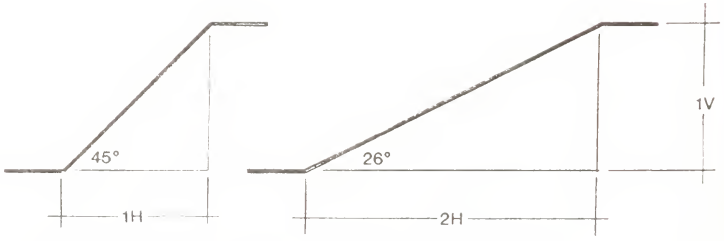

START
Previously Planted or Seeded
Vegetation Present
Vegetation Mostly Weeds
See Figure 13
Poor Timing or Bad Weather after Planting – See Section 5.6
Inappropriate Seed Mix – See Section 5.3
Vegetation Mainly Grasses and Legumes
Stunted Growth
Wilted, Leaf edges brownish – Lack of Moisture – See Section 4.3.6
Discoloured – Low Nutrients or Contamination – See Section 4.3.2, 4.3.5
Zonal Growth
Plants growing in wheel marks or tillage troughs – lack of moisture – See Section 4.3.6
Plants growing mostly at the bottom of the slope
Surface is Tilled – No soil moisture – See Section 4.3.6
Stones and Pebbles show clearly on surface – Erosion of Seeds etc. to Lower Slopes – See Section 4.2
Patchy Growth
Gas Smell and/or Stunted Brown Leaves – Landfill Gas Emission – See Section 4.5
Leachate or Stains Visible – Leachate Seep – See Section 4.4
Barren Areas
Evidence of Erosion
Stones and Pebbles exposed on surface – Sheet Erosion – See Section 4.2, 4.3.1
Rill Development – Rill Erosion – See Section 4.2
Gully Development – Gully Erosion – See Section 4.2
No evidence of Erosion
Cracked Surface (Clay) – Lack of Moisture – See Section 4.3.6
Small Sand Dunes (Sand) – Lack of Moisture – See Section 4.3.6
Not Previously Planted or Seeded – See Section 6.2

FIGURE 6: KEY TO PROBLEM IDENTIFICATION





Slope Angle = 100%, or 45°

Slope Angle = 50%, or 26°

Legend	Slope Terminology	FIGURE 7
	LANDFILL REVEGETATION MANUAL	

- Slope angle is defined as the angle of the surface from the horizontal (Figure 7). Slope angle can be expressed in degrees, or as a percent slope, calculated by dividing the "rise" by the "run", or as a Vertical:Horizontal Ratio using the vertical distance (rise) to the horizontal distance (run).

- A slope of 1 Vertical(V):2 Horizontal (H) (i.e., 50% slope, 26°) is the maximum on which vegetation can reasonably be established and maintained, assuming ideal soil with low erodibility and adequate moisture holding capacity (8, 24, 34).

- A slope of 1V:3H (i.e., 33% slope, 18°) is the maximum for establishing acceptable vegetation cover on less than ideal soils, and the maximum slope for safe maintenance (6, 24, 34).

- A slope of 1V:4H (i.e., 25% slope, 14°) is an optimal maximum for vegetative stability (24, 34).

How to Overcome Problems Caused by Steep Slopes:

- Ideally, when planning and designing a landfill site, the slopes should be kept to less than 25% (i.e., 1V:4H), with terraces or benches built in (Figure 8).

- The slope must be mechanically stable prior to revegetation.

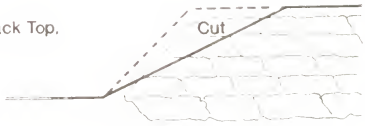
- Establishing a dense, fibrous rooted vegetative cover could well be the only option for most existing landfills. The use of soil amendments, erosion blankets and special techniques may be essential (Section 4.2).

- One way to overcome the problem of steep slopes is by changing the configuration of the slope, reducing the steepness by lengthening the horizontal run of the slope (Figure 8). This involves filling land adjacent to the toe of the slope or cutting back the top, both of which are not usually feasible on existing landfill sites (12, 18).

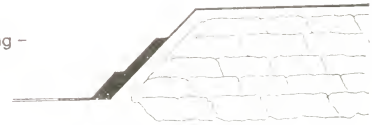
Existing Steep Landfill Slope

Steep Slope Reduced by Filling on Adjacent Land.

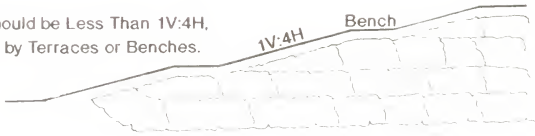
Steep Slope Reduced by Cutting Back Top, Exposing Cap and Contents.



Slope Length Reduced by Terracing – Creating Short, Steep Slopes.



Ideal Slopes Should be Less Than 1V:4H, and Interrupted by Terraces or Benches.



Legend	Remediation of Steep Slopes	FIGURE 8
	LANDFILL REVEGETATION MANUAL	

- Another way to overcome long steep slopes is to terrace the sideslope into a series of short steep slopes. This solution is less than ideal (46), and may not be viable (Figure 8).

4.2 EROSION

Description of Problem:

- Erosion is the loss of surface soil material due to the action of water or wind.

- Erosion by water is likely to be the primary concern on landfill slopes.

- On sites with sandy soils on the surface, wind erosion could also be a significant erosion factor.

- In areas where slope failure has occurred, the resultant scar may develop into an erosion problem.

Recognition and/or Testing:

- Sheet erosion is the removal of a thin layer of soil, and is recognized by patches of light coloured material surrounded by darker or vegetated soils, or by the exposure of previously buried pebbles and stones (Figure 9)(18). Eroded soil materials are often deposited at the toe of the slope.

- Rill erosion is described as the removal of soil in small but recognizable channels, resulting in large volumes of soil loss. It is most serious on sites with loose topsoil or bare, compacted slopes, and in areas subject to intense storms.

- Gully erosion results in deeply cut channels. These may have developed from rills which are allowed to erode, from drainage channels flowing downslope, or from paths or tracks made by machinery going upslope. The rate of erosion relates to the amount and velocity of water runoff, soil characteristics, and size and slope of the gully formation (18).

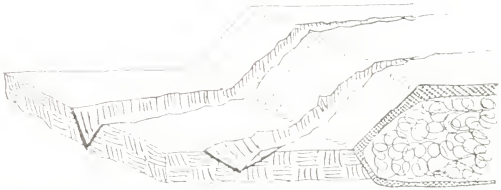
Sheet Erosion

Rain loosens soil particles and flows overland, depositing soil materials at the toe of the slope.

Rill Erosion

Surface water begins to form small channels.

Gully Erosion



Heavy surface flows erode the surface, creating deep channels, and possibly exposing landfill contents.

Legend	Erosion Types	FIGURE 9
Waste Native Soil	LANDFILL REVEGETATION MANUAL	

How to Overcome Erosion:

- Ideally, when planning and designing a landfill site, the covering topsoil should have low erodibility such as loam (equal parts sand, silt and clay - Section 4.3.3). Further erosion control can be achieved with organic litter amendments, such as peat or sludge (Sections 4.3.4 and 5.4.2) or a mulch cover (Section 5.4.1).

- On existing soils the establishment of a vegetative cover is usually the primary control - a cover of 60% is effective against sheet erosion since the root system is the main factor in soil stabilization. The level of effectiveness to reduce the impact of raindrops (46) and to resist sheet erosion (45) varies with species and density.

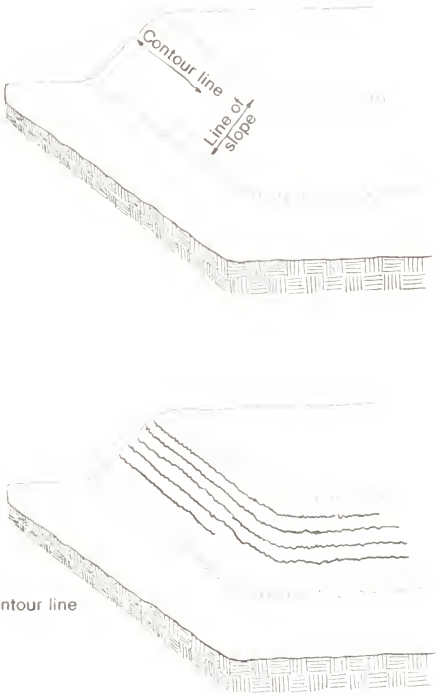
- Rills can be removed by tillage (18), prior to stabilization with vegetation.

- Tillage and planting equipment should be operated across the slope, and not up or down the slope (Figure 10). This is referred to as "contouring" and it helps resist erosion because each row acts as a barrier to the flow of water (18).

- The maximum length on which contouring is effective is: 60 m on 8% slope; 30 m on 10% slope; 24 m on 12% slope; and 18 m on steeper slopes (18).

- Gullies require immediate action. This can be as simple as rebuilding and reseeding. There may be a need to reduce slope angles by regrading longer slopes, and to improve soil characteristics on which vegetation can be established.

- Vegetative cover can be simulated and/or supplemented by using mulches and/or erosion blankets to provide short term relief from erosion until the seeded vegetation can become established (6).



CONTOURING

Tilling or Ripping along a contour line

(i.e., across the slope.)

Legend	Contouring	FIGURE 10
	LANDFILL REVEGETATION MANUAL	

4.3 SOIL CHARACTERISTICS

4.3.1 Compaction

Description of Problem:

- Soils low in organic matter content become hard-packed from passage of equipment, especially machines with smooth or rubber tires (8, 22, 28).

- Space between soil particles is reduced (Figure 11), resulting in:

  - changes in nutrient availability to plants (2)
  - lowered oxygen concentrations leading to less root growth (2, 15, 19)
  - lowered infiltration of water leading to reduced root growth (2, 8, 15, 22, 28)
  - hindered root growth due to more dense structure of soil (2, 8, 15, 19, 28).

- Soils with a wide range in particle sizes are particularly susceptible to compaction (2).

Recognition and/or Testing:

- Excessive erosion is taking place.

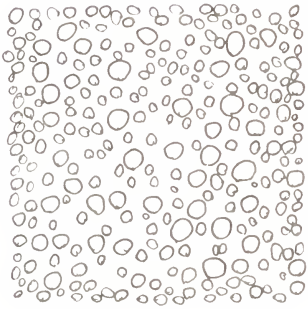
- Digging the surface soils is difficult.

- Plants are observed to be stunted, with shallow or malformed root systems (2).

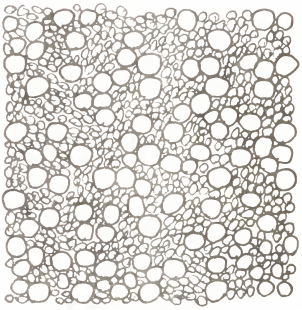
- Soil laboratory tests indicate the sample has a high bulk density (i.e., very little air space is left).

How to Prevent or Overcome Soil Compaction:

The objective is to improve soil structure by increasing the space between soil particles. This is important to facilitate plant growth.



Voids between soil particles facilitates movement of soil gases, moisture, and root penetration. If tested by a soil laboratory, this soil would have a low bulk density.



The void size between soil particles is reduced. Gas and moisture movements are restrained. Roots cannot easily penetrate. This soil has a high bulk density.

Legend	Soil Compaction	FIGURE 11
	LANDFILL REVEGETATION MANUAL	

- Although the landfill cap is intentionally compacted to reduce permeability, the placement of the topsoil cover should be undertaken with care and limited handling to avoid compaction. It should be laid full depth in a single layer on the roughened cap, rather than several thin layers, to avoid repeated passage of heavy equipment.

- On existing topsoil covers, rip the top layer to 20 cm (or less if topsoil cover is thinner than 20 cm) by cultivating on the contour using equipment such as subsoilers and multiple-shank rippers that do not have smooth or rubber tires (2, 8). This step can be reduced to surface scarification for those sites without a topsoil cover in place.

- Incorporate soil amendments into the topsoil cover material to increase the content of the organic matter (20, 21). Humus, peat moss, manure, compost, leaf mulch or MOE approved sewage sludge can be used.

Caution:

- Work should be done when the soils have dried enough to support equipment, and are no longer soft and sticky. Wet soils are susceptible to compaction. (20, 21, 22, 28).

- The final topsoil cover should be added in one layer rather than a series of thin ones (20, 21, 28).

- When topsoil is placed on slopes, especially compacted clayey material, there should be some preliminary cross-slope tilling of the cap to roughen it (Section 5.5), and tilling of the topsoil into the cap material, so as to prevent slippage of the topsoil layer when wet.

- Minimize mechanical handling of soils during stockpiling and respreading operations (2).

- It will take several years for the soil structure to improve, therefore, avoid or minimize the use of equipment on the slope.

- Reference to the cover does not mean the landfill cap. If the slope does not have a covering layer of topsoil on the low permeability cap and if placement of such a cover layer is not possible, tillage or ripping of the cap must be done with caution to avoid damage to the low permeability cap.

4.3.2 Soil pH

Description of the Problem:

- Soil pH is a measure of the acidity or alkalinity of the soil. Values less than 6 indicate acidic soils, those greater than 8 are alkaline or basic soils. A pH value between 6 and 8 is considered neutral (8), and the best range for vegetation management.

- The pH is dependent on soil type.

- The effects of low or high pH include:

  - Changes in the availability of nutrients:

    Several essential elements tend to become less available as pH is raised from 5 to 8. These include iron, manganese and zinc. Molybdenum availability is raised at higher pH's. A pH of 6 -7 promotes the availability of plant nutrients (9).

  - Increased toxicity of elements and/or contaminants:

    At pH values below about 5, aluminum, iron and manganese are often available in sufficient amounts to be toxic to the growth of some plants. At very high soil pHs, the bicarbonate ion is sometimes present in sufficient amounts to interfere with the normal uptake of other ions.

  - Changes in the decay of organic matter and, therefore, release of nutrients:

At low pH values, the availability of certain nutrient bases, such as calcium, potassium, magnesium, increases (9).

Recognition and/or Testing:

- Determination of soil pH can be done on soil submitted to a soil testing laboratory for analysis of nutrients and fertilizer requirements. A fee is charged for this service. A list of facilities is presented in Appendix B. Collect samples as outlined in the testing procedure for soil nutrients (Section 4.3.5).

- Soil pH kits are available from various scientific supply houses. However, these kits will not indicate when there is a problem nor how to overcome one.

How To Adjust Soil pH

- Ideally, the topsoil cover will come from a source with an existing pH of 6 to 8.

- Alkaline soils (pH greater than 8) are unlikely to be encountered on a landfill.

- Acidic or slightly acidic soils (pH less than 6) can be amended by the addition of agricultural lime (Section 5.4.3). Rates of application are provided with the analysis of pH by a soil testing laboratory.

4.3.3 Texture

Description of the Problem:

- Texture is the "feel" of the soil.

- It is dependent on the proportion of fine to coarse-grained particles in the soil.

- It affects the ability of the roots to penetrate and anchor in the soil, and the availability of water and nutrients.

How to Overcome Low Organic Matter:

- Ideal is to have soil with 5-20% organic matter (6).

- The content of organic matter in the soil can be improved by adding humus, peat moss, manure, compost or sewage sludge (20, 21), (Section 5.4.2).

- On sites not yet completed, stockpile topsoil with a good content of organic matter. This soil should be a dark brown or black colour.

- Landfill operations which are composting leaves and chipped wood have a valuable resource for improving the organic matter content of the topsoil cover on completed portions.

4.3.5 Nutrients

Description of Problem:

- Poor plant growth or limited establishment may result from soil nutrient levels which are too low or too high. This is true especially for nitrogen, potassium and phosphorus.

- Sandy soils are particularly prone to low nutrient status because they are inherently low in nutrients and because the nutrients which are present are easily leached out of the soil (8).

- Nitrogen (N):
  - probably the most critical nutrient (8);
  - needed for plant growth but is easily lost from the soil (8, 34);
  - requirements depend on the amount of existing organic matter, soil texture and seed mixture to be used (34).

- Phosphorus (P):
  - often bound to other components of the soil, therefore, not readily lost (8, 34);

- its availability to plants depends on the pH of the soil with higher rates of application needed for both acidic and alkaline soils (34).

- Potassium (K):
  - moderately mobile in the soil, therefore, leached out slowly (8, 34);
  - less important for grass mixtures than legumes (34);

- Calcium (Ca) and Magnesium (Mg):
  - not usually deficient except in acidic soils;
  - liming materials, such as dolomitic lime, contain both Ca and Mg.

- Sulfur(S):
  - present in rain water and in manure or commercial fertilizers (i.e., sulfur coated urea);

- Heavy Metals and/or Contaminants:
  - some metals are micro-nutrients (Cu, Zn) but may become contaminants if their concentration is too high;

  - other chemicals can be present in the soil in concentrations which can interfere in normal plant growth.

Recognition and/or Testing:

- The three most important nutrients in terms of plant growth, are nitrogen (N), potassium (K) and phosphorus (P). Tests for potassium and phosphorus are included in the basic test done by soil testing laboratories (Appendix B). Tests for nitrogen, however, are usually done separately at additional cost. It is advisable to discuss testing for nitrogen requirements with the soil laboratory.

- Testing should be done prior to planting in order to determine fertilizer requirements. Generally the soil test laboratory will make inquiries as to the crop planned and will make recommendations to suit. For example, a landfill

operator will desire a low maintenance turf, and the laboratory will make appropriate fertilizer recommendations.

- If soil samples are to be tested for heavy metals or contaminants, arrangements should be made in advance of collection to determine sample collection procedures and costs.

- The general procedures for collecting a representative composite sample of soil for the slope are:

  a) Take soil samples when the soil is workable - do not obtain when the soil is frozen or saturated with water.

  b) Collect sub-samples of soil only from those areas with similar soil characteristics. Obtain one composite sample for each slope.

  c) Use a soil collecting tube, trowel or spade to obtain each sub-sample. Sample only to a depth of 15 cm; place sample in a clean bag or pail. Clean the tube or spade between uses.

  d) Collect additional sub-samples from the area of concern, about 4 sub-samples per hectare, to obtain one large composite sample (about 1/2 litre of soil is needed).

  e) Transfer soil to box provided by the laboratory (or use clean plastic bags which have been well-labelled with date, name, location).

  f) Send labelled composite sample(s) to testing laboratory. Indicate the type of crop that is to be grown (e.g., grass, legumes, grass-legume mixture) and if manure or sludge is to be used.

Important: To know where the composite sample came from, note on your check sheet where the different sub-samples were taken.

How to Overcome Poor Nutrient Conditions:

- Ideally the topsoil cover will come from a source with an acceptable nutrient status. If it previously supported vegetation, it should be capable of growing vegetation when used on the landfill.

- The nutrient status of the existing soil can be improved by the addition of fertilizers. The type and amount of fertilizer required will be determined by testing the soil, and the type of vegetative cover to be grown. Fertilizer requirements will be provided by the soil-testing laboratory.

- The laboratory will also indicate the appropriate time frame in which to apply fertilizer, but the following general rules apply:

  - Best application times are: spring (as soon as snow melts); late May; early July; and early September.

  - Fall fertilization is recommended for established turf (39) because it is during the fall that root development and nutrient storage take place. As well, it means no equipment needs to drive over soft ground in the spring.

  - Do not apply annual fertilizer requirements in a single application since this may burn the crop;

  - Fertilizers should be spread prior to a rain or be watered after application.

Caution:

Due to the ease with which some nutrients (especially nitrogen), are washed from the soil, it may be necessary to add fertilizer annually. This may require a soil test every year until the vegetation becomes established and, thereafter, a test may be useful every second year. Fertilizer requirements may change from year to year. It is important to

determine appropriate application rates each time in order to avoid a build up of less mobile elements, such as potassium and phosphorus. Assistance and advice can be obtained from the soil testing laboratory, the fertilizer supplier, the local Ontario Ministry of Agriculture and Food (OMAF) office, or an agricultural college.

4.3.6 Low Soil Moisture

Description of the Problem:

- Soil moisture affects plant growth and establishment.

- Low soil moisture can be caused by a number of factors including coarse soil texture, lack of rainfall, thinness of cover soil, small amount of organic matter in the soil, as well as steep slope and compaction, both of which accelerate runoff (20).

- The clay cap can be badly damaged by excessive drying, leading to severe cracking (23, 30).

Recognition and/or Testing:

- Visual
  - soil which is easily blown away and/or cracks on the ground surface, usually indicates dry conditions;
  - poor establishment of plant growth after seeding.

How to Overcome Low Soil Moisture Conditions:

- Ideally, the topsoil cover will have adequate proportions of clay and organic matter, both of which help retain moisture.

- The key to improving low soil moisture conditions is to make the best use of available precipitation (27). This can be achieved by reducing runoff, improving the soils infiltration rate and water holding capacity, and reducing evaporative losses.

- Ripping on contour (Figure 10) of compacted and low permeability soils before planting will slow runoff, hold surface water, and increase infiltration (27).

- Irrigation of existing sites could be undertaken but it is expensive and requires constant maintenance.

- Incorporation of organic matter into existing soil prior to planting will improve soil structure, water permeability in clayey soils, and water holding capacity in sandy soils (20).

- Mulching after planting, with woodchips, bark, straw or plant debris, will slow runoff and reduce the amount of water lost to the atmosphere (evaporation) while the vegetation is getting established. An outline of different mulches is provided in Sections 5.4.1 and 5.4.2.

- Combination of the above.

- If a seeding program is unsuccessful because of poor moisture conditions, there may be a need to reseed when soil moisture conditions are more suitable (Section 5.6).

4.4 LEACHATE SEEPS

Description of the Problem:

- Leachate is the liquid effluent produced from the decomposition of the landfill contents and/or liquids released from decomposing containers in the landfill and/or water which has percolated into the landfill through the cap material (precipitation) or has entered from the ground water.

- Leachate seeps or springs result when the leachate emanates from the sideslope or cap of a landfill, and flows on the surface.

- Leachate can be toxic to plants, depending on the nature of its source(s) and its concentration.

- Leachate toxicity and volume of flow can change over time.

- The presence of leachate at the surface can be a limiting factor in the establishment of vegetation, and is likely a violation of the Certificate of Approval.

Recognition and/or Testing:

- Dark reddish brown, "rusty" in appearance, leaving stains on soil and plant material.

- Foul smell.

- Vegetation may be dead in the vicinity of a new seep.

- Vegetation may be absent in the vicinity of an old seep.

- Leachate may puddle or flow, depending on topography.

How to Eliminate Leachate Seeps:

- The seriousness of a leachate seep of any size should not be underestimated. It is recommended that the landfill operator contact the MOE to determine the significance of these problems as they occur, and to identify environmentally acceptable solutions to resolve them. This is likely a requirement of the Certificate of Approval.

- The current treatment is to reduce infiltration by encouraging water to shed off the landfill using increased compaction and clay, or to extract and treat the leachate. Some recent research involves spray irrigating leachate on a soil-vegetation ecosystem (13, 35, 36, 40).

4.5 LANDFILL GAS EMISSIONS

Description of the Problem:

- The decomposition of landfill materials produces, among other things, gases, such as methane, carbon dioxide, and hydrogen sulfide (rotten egg smell, poisonous).

- Gas production is dependent on refuse composition, moisture content, pH, age of waste, and climate (temperature) (10).

- The concentration of gas contamination is not necessarily uniform over the site (21) or over time (26).

- Landfill gases displace soil oxygen, impairing root development, thereby limiting the establishment of vegetation (the gases may or may not be toxic to plants).

Recognition and/or Testing:

- Irregular areas of dead or dying vegetation are visible.

- There is a rotten egg smell or rotting garbage smell in the soil.

- There is dark stained soil just below surface.

- The presence of gas can be verified by testing for methane, carbon dioxide, absence of oxygen content, with appropriate field equipment.

- Gas emissions can cease, or be intermittent, depending on the cause or seasonality of production factors, such as temperature and precipitation.

How to Eliminate Gas Emissions:

- It is recommended that gas emission problems be reviewed with MOE to determine the significance of the problem, and to identify an acceptable solution to resolve it.

- Leachate toxicity and volume of flow can change over time.

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How to Eliminate Gas Emissions:

- It is recommended that gas emission problems be reviewed with MOE to determine the significance of the problem, and to identify an acceptable solution to resolve it.

- Gas emissions can be intercepted before entering the root zone by an original or retrofit venting system placed below the compacted cap.

- Preventing freezing and/or drying of the compacted clay cap will provide more resistance to surface gas emissions as well as to infiltration of precipitation (23).

4.6 EXISTING VEGETATIVE COVER

Description:

- The existing vegetative cover could be planted or self-established vegetation on the finished or undisturbed cover of the landfill.

Recognition/Testing:

- Landfill cover may be fully vegetated, patchy, or barren.

- Vegetation may be zonal in location, for example the top of the slope could be barren while vegetation is well established at the toe of the slope.

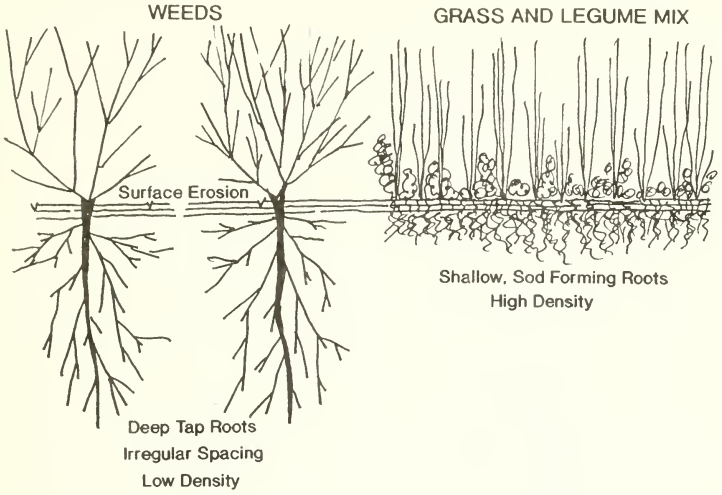
- Species present could have been planted or could be from seeds blown in or originally present in the soil cover.

- Planted species could include grasses (such as timothy, bromé grasses, bluegrasses, rye grasses), and clover (red, white, alfalfa). These may appear in rows and/or in even density (Figure 12a).

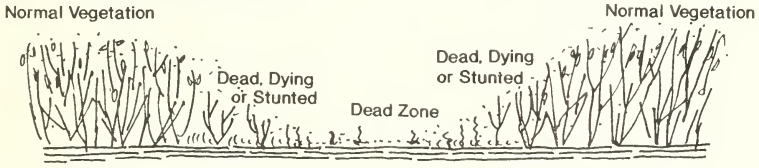
- Weed species could include barnyard grasses, green foxtail, quackgrass, crabgrass, thistles, ragweeds, buckwheats, pigweeds, and Russian thistle (tumbleweed). These may be irregular and widely spaced (Figure 12a). Identification of common landfill weeds is provided in Appendix D.

- Woody species (trees, shrubs) may be present.

a) Comparison of Weed Growth and Planted Cover



b) Cross Section of Typical Gas Kill



Legend	Vegetation Details	FIGURE 12
	LANDFILL REVEGETATION MANUAL	

- Barren soil, or dead, dying, or stunted vegetation (Figure 12b) could indicate toxic conditions (landfill gases, leachate, metal contamination, etc.), inadequate soil nutrients, inadequate soil moisture, over-compacted soil, or chronic surface erosion.

- Use Key (Section 3.2) to identify potential problems.

How to Establish or Improve a Vegetative Cover:

- Where existing vegetative cover is sparse it can be improved with fertilizers (after soil testing) and over-seeded with appropriate species in early spring or fall.

- Where existing vegetative cover is to be replaced, it should be tilled into the soil as a source of organic matter, followed by the revegetation program.

- Weeds in planted areas can be controlled by appropriate herbicides, followed by fertilizer and reseeding at the correct time. The use of herbicides should follow correct procedures and avoid contamination of nearby watercourses. Some herbicides can destroy species in the nurse crop or permanent species, and so, caution should be exercised. Contact the local OMAF office for assistance regarding herbicide use. (Refer to Section 5.0 for preparation and seeding guidelines).

- Weeds growing in areas not previously planted should be prevented from reseeding, by mowing or spraying; the area should be prepared and seeded at the correct time, in accordance with the revegetation program.

- Woody material (shrubs and trees) growing where root penetration of the cap would be undesirable should be destroyed by physical removal and/or appropriate herbicides. The area should be reseeded at the correct time.

- Barren, thin, and patchy spots in areas previously seeded should be tested for soil bulk density and nutrients. If gas and/or other contamination are suspected, the site can be tested accordingly. Based on test results the site should be prepared and seeded at the correct time.

5.0 PLANNING THE REVEGETATION PROGRAM

In planning the revegetation program, the successful establishment of a living protective cover should take into account the following:

- Appropriate plant material must be selected for the intended use.
- The intended use must be reasonable and feasible, given the landfill conditions.
- Adjustments must be made to the topsoil cover in order to provide optimum conditions for the establishment and growth of the selected vegetation.
- The vegetation must be established at the correct seeding time with proper techniques.
- If needed for an intended use, the established vegetation must be appropriately managed for the planned use.
- Certain minimum standards should be set so as to judge the relative success of the restoration program and provide an indication of where additional effort is required (38).

These issues are discussed in the following sections.

5.1 REVEGETATION OBJECTIVES

Besides the obvious aesthetic requirement of revegetating a landfill site, the following objectives should be satisfied by the vegetative cover:

- To provide sufficient density of cover (foliage and stems) to reduce soil loss by rainfall impact.
- To provide sufficient density of shallow fibrous roots to bind the soil, especially at the surface, to resist the eroding forces of overland flowing water, and the cracking action of both the freeze-thaw cycle and the wet-dry cycle.
- To create more resistance at ground surface to overland flow and consequently reduce its velocity (7).
- To reduce the depth of infiltration of precipitation into the cap by facilitating evapotranspirative losses of water from the upper levels.
- To be self-sustaining and low maintenance with no danger of penetrating the cap.
- To be capable of withstanding the intended end use.

5.2 CHARACTERISTICS OF AN IDEAL VEGETATIVE COVER

To satisfy the objectives, the plant species individually and/or collectively should have these characteristics:

- Easy to establish, with good growth in the first growing season.
- Sod forming with shallow, fibrous roots and multiple stem growth habit.
- Self propagating by seeding, by root suckers, and/or perennial lifecycle.

- Low nutritional demands, tolerant of pH variation, ability to fix nitrogen, adaptable to variations in physical habitat.

- Reasonable tolerance to local climatic extremes. Drought resistance is especially important where topsoil cover is thin or absent (29).

- Inoffensive, non-poisonous species. Appendix D identifies noxious weeds and typical landfill weeds.

- Requires minimum attention after establishment.

- Attractive, or at least inoffensive, in appearance.

5.3 SPECIES AND MIX SELECTION

It is impractical in this manual, to recommend a mix or series of mixes that would be appropriate for all site conditions. Rather, the intent of this section is to provide the reader with an understanding of what factors dictate the mix composition and what role is played by the different components.

Several factors affect the successful establishment of a particular mix of plant species: soil type, nutrient and moisture conditions, species life cycle and morphology (perennial versus annual and depth of rooting etc.), climatic zone (some species are not tolerant of our more northern climates) and proposed end use of the site (e.g., aesthetics, durability).

Since it is unlikely that single plant species can meet all of the required characteristics, it is advantageous to use a seed mix in which the species and proportions of each have been carefully determined. Typically, the seed mix has two main components: the nurse crop and the permanent species.

The nurse crop seed mix usually contains annual grasses which produce a rapidly growing and effective ground cover with a large, shallow root mass, combined with annual legumes, which fix soil nitrogen (32).

Usually applied at a relatively low seeding rate, the nurse crop offers immediate soil stabilization to reduce erosion and prevent loss of the permanent crop seeds. As well, it offers an improved microhabitat by partially blocking the sun and wind, and maintaining high humidity at the soil surface. Nurse crop species should be those which begin to mature in early summer, to avoid competing with the permanent species during the summer period of moisture stress (33). The death of the nurse crop adds organic matter to the soil which will help avoid soil erosion and moisture loss, and contribute nutrients to the soil.

Several examples of nurse crops are presented in Table 1 including: Oats (*Avena sativa*), Annual Ryegrass (*Lolium multiflorum*) and Foxtail Millet (*Setaria italica*). Those species described as providing temporary cover on Table 1, are generally suited to serve as nurse crop species.

Having identified a preferred nurse crop, the next step is to round out the seed mix with several perennial grasses and legumes. An ideal mix would include two to five grasses and one to four legumes.

The permanent species may be seeded at the same time as the nurse crop, or may be seeded into the mulch created by the nurse crop after it has died off (41). A reasonable cover can generally develop by the end of the first growing season, and a stable cover in two to three years (12).

Table 1 provides a long list of species suited to different areas of the province and to varied soil conditions. The selection of components for a mix requires a careful evaluation of site specific conditions in conjunction with the interaction of species in a mix. This advice should be sought from the Agricultural Representatives at the local office of the Ministry of Agriculture and Food. In non-agricultural areas of northern Ontario, contact district offices of the Ministry of Northern Development and Mines. Appendix F identifies how to find seed suppliers, and Appendix F a list of OMAF offices.

TABLE 1: LANDFILL COVER SPECIES

SCIENTIFIC NAME	COMMON NAME	RANGE			SOIL MOISTURE		OBSERVED OR DOCUMENTED METHANE TOLERANCE	LIFE CYCLE		COMMENTS (eg. ROOTING CHARACTER, pH AND METAL TOLERANCE
		DECIDUOUS	GT. LK.	BOREAL	MOIST	DRY		PERENNIAL	ANNUAL	
GRASSES										
Agropyron elongatum	Tall Wheatgrass	X	X		X			X		prefers alkaline areas, bunchgrass, short rootstock
A. repens	Quack Grass	X	X		X	X		X		
A. Smithii	Western Wheatgrass	X	X	X		X		X		deeply rooted, sod-forming
* Agrostis alba	Red top	X	X	X	X			X		dense turf, dense shallow feeding roots, excellent soil binder
A. capillaris	Bent Grass	X	X		X			X		intolerant of low temperatures
A. scabra	Tickle Grass	X	X	X	X			X		shallow fibrous roots, short-lived perennial
Andropogan gerardii	Tall Bluestem	X	X		X			X		important prairie species
A. scoparius	Little Bluestem	X	X		X			X		important prairie species
Arrhenatherum elatius	Tall Oatgrass	X								
Avena sativa	Oats	X	X	X					X	temporary cover
* Bromus inermis	Smooth Bromegrass	X	X		X	X		X		rhizomes
Calamofila longifolia	Prairie Sandreed					X		X		
Dactylis glomerata	Orchard Grass	X	X		X	X		X		fibrous roots
Deschampsia caespitosa	Tufted Hair Grass	X	X	X	X			X		fibrous roots
Echinochloa crusgalli	Barnyard Grass	X	X	X	X		X		X	temporary cover, considered a weedy species
Elymus canadensis	Canada Wild Rye							X		deep, extensive root system
Eragrostis curvula	Weeping Lovegrass									
Festuca arundinacea	Tall Fescue	X	X			X				deeply rooted, some drought tolerance, does well with Bromus and Phleum
F. ovina	Sheep Fescue		X					X		fibrous roots
F. rubra	Creeping Red Fescue	X	X		X			X		deep feeding roots, enimnonly cultivated
* Lolium multiflorum	Annual Ryegrass	X	X						X	temporary cover
* L. perrene	Perennial Ryegrass				X			X		relatively shallow roots
Panicum capillare	Witch Grass					X			X	fibrous roots
P. virgatum	Switchgrass	X	X	X		X		X		sod forming, short stout rhizomes
Phalaris arundinacea	Reed Canary Grass	X	X		X		X	X		wet places
* Phleum pratense	Timothy	X	X	X	X	X		X		primarily shallow fibrous roots, commonly seeded for hay and pasture
Poa compressa	Canada Bluegrass	X	X			X		X		deep rooting system, withstanda low nutrient levels
* P. pratensis	Kentucky Bluegrass	X	X	X	X	X		X		dominated by dense shallow rooting system, some deeper feeding roots
Secale cereale	Winter Rye								X	temporary cover
Setaria italica	Foxtail Millet								X	temporary cover
S. viridis	Green Foxtail						X		X	fibrous roots, weedy species introduced from Europe
Sporobolus cryptandrus	Sand Dropseed	X	X			X		X		deeply rooted bunchgrass
Triticum aestivum	Winter Wheat								X	temporary cover
LEGUMES										
Cornilla varia	Crown Vetch				X	X		X		drought tolerant
Lotus corniculatus	Birdsfoot Trefoil				X	X		X		can tolerate low pH, should be planted in a mix with grass
Medicago sativa	Alfalfa								X	deeply rooted
Melilotus alba	White Sweetclover				X	X			(X)	biennial, requires higher pH
M. officinalis	Yellow Sweetclover				X	X			(X)	biennial, better than white Sweetclover for dry conditions
Trifolium hybridum	Alsike Clover				X			X		dies after two years, tolerates wet conditions, well-suited to acid soils
T. pratense	Red Clover				X			X		
* T. repens	White Clover				X	X		X		density of cover decreases over time, shallow rooted crop

THE BOREAL — The boreal area occupies much of north-eastern Ontario, north of Dryden, Wawa and Kirkland Lake.

G - GREAT LAKES - ST. LAWRENCE — This region includes the land area and north of the line extending approximately from Goderich to Cambridge to Kingston.

D - DECIDUOUS — This is the smallest of the three regions. It occurs south of the Great Lakes - St. Lawrence region and includes most of southwestern Ontario.

Note * These species are recommended for use. However, their rooting character and topsoil depths are limited. They have been selected primarily for their shallow rooting character (and therefore less likely intrusion on cap) and their ability to tolerate low moisture and nutrient conditions. Adapted from [11], [41], [42], [43] and [47].

The intent of Table 1, is to provide a starting point, where each landfill owner/operator can develop a preliminary list of species. Some of the references listed in Section 10.0 would be useful to examine in conjunction with Table 1, to gain an appreciation for the size and appearance of each species.

Species are presented with both the scientific and common names. It is best to refer to the scientific names when seed is ordered. The problem with common names is that frequently, one species can have several common names, often overlapping with a completely different plant. The requested seed may be unavailable - the seed supplier may offer a substitute cultivar which could provide equal or better performance.

The Range section of Table 1 gives the reader an impression of where the species would be best planted. The regions are described on the bottom of Table 1. Generally, most of southwestern Ontario falls into the deciduous region, most of central Ontario into the Great Lakes St. Lawrence region and northern Ontario into the boreal region.

Relative soil moisture preferences are indicated. Fewer species are able to tolerate the dry conditions often found on sandy landfill covers which are frequently encountered in northern Ontario. Tolerance to combustible landfill gases (or lack of oxygen) in the rooting zone, is not well documented in the literature. The few species observed during the field program contributing to this manual, that demonstrated some tolerance, are indicated.

Life cycle is another category on Table 1, that can be valuable in the selection of a cover crop. Perennial species are those that develop year after year from the same rootstalks. Annuals have a one year life cycle, dependent upon seeding to establish a crop the following year. The comments provided indicate other information that would be useful during planting considerations. Many comments focus on the rooting characteristics of the species.

Seven species on Table 1 are given a specific recommendation for planting on typical landfill sites where the depth of the soil cap and/or cover is limited. Those species are recommended for their shallow rooting systems, which will not pose a threat to the

integrity of the cap. The seven species could be suitable as a mix with proportions and seeding rates to be determined on a site by site basis in consultation with agencies offering advisory services.

The use of legumes in a vegetation program takes advantage of their ability to fix atmospheric nitrogen, with the assistance of a soil bacterium (*Rhizobium* spp.). Because this bacterium may not be present in the harsh, sterile soils on a landfill site, it is typically added to the seeds as an "inoculum" prior to planting. The supplier of the seed mix should be consulted to verify that the seeds are inoculated with the correct strain of *Rhizobium*.

5.4 SOIL AMENDMENTS

Soil amendments are natural or manufactured products, or by-products of other processes, which can be applied to or incorporated into the soil to improve general growing conditions.

5.4.1. Mulches

Mulches are essentially materials that cover the ground surface to prevent erosion and to encourage seedling establishment and growth.

- Erosion from raindrop impact can be reduced immediately by applying mulch (6).
- Mulch also reduces water velocity and traps silt, both of which reduce erosion (6).
- Seedling establishment and growth are encouraged by mulch which holds moisture, increases soil temperature for germination, and improves soil structure (6).
- Several types of mulch are available: straw, sawdust, straw with wood fibre, compost, sludge, and erosion mats made of organic components.

- Nylon monofilament materials are not as effective as natural organic mulches due to nylon's lack of moisture holding ability and inability to trap soil particles (25).

- Materials which are fibrous and interwoven are more effective in reducing erosion because they stay in place and have good soil contact (25).

- Loose mulches, such as straw, may be ineffective if they can blow away, or move downslope during rainfall (25). The use of a crimper is recommended to push the straw into the soil. The resultant whisker dams trap sediment, reduce water velocity, and offer a point of entry into the soil for precipitation (27).

- Mulches can be applied in mechanical or hydraulic operations.

- Mulching by itself is not a means of permanent soil stabilization. It offers temporary surface protection until the vegetation becomes established (6). It is unlikely that mulches will hold on slopes steeper than 50% (6).

- Mulch recommendations:
  Many products and techniques are available for erosion control, not all of which are effective at controlling erosion. In a recent research project for the Ministry of Transportation (1), three commercial mulches were compared at five rates of application to determine their effect on turf establishment as compared to a straw mulch. At an early observation date the straw mulch and one of the commercial mulches (Fibramulch) provided excellent erosion protection which proved to be effective throughout the season. As the vegetation began to develop, straw was clearly superior to the commercial mulches. By the end of the five month period, the vegetation was comparable for all commercial mulches and straw. The early season protection against erosion provided by straw and the one commercial mulch is a significant advantage in successful erosion control. This experiment also confirmed that 1600 kg/ha is a reasonable

minimum mulch application rate. Other research (44) indicates that good protection against erosion can be provided with:

- jute netting;
- wood excelsior mat;
- Fibreglas anchored with asphalt; and
- wood chips, hay, or ground corn cobs with asphalt.

Effective protection after one year is provided by the wood excelsior mat and hay with asphalt (16). These are relatively expensive mulch applications which are most appropriate for small scale "problem" erosion sites.

5.4.2 Sewage Sludge

- The application of sludge can provide supplementary nutrients and organic matter, and improve moisture holding capacity. Contact the Ministry of Environment for locations of acceptable sludge sources).

- Recommendations:
  - A single, initial application in sufficient quantity immediately improves cover material deficiencies. It also provides long term benefits through the slow release of nutrients.

  - Excessive use of sludge is not recommended because it may cause ground and surface water contamination, and the build-up of toxic levels of soil nutrients and/or contaminants (48).

  - The nitrogen in sewage sludge is used more effectively when sludge is applied in the spring and immediately worked into the soil (4).

  - Rates of application and guidelines for use can be determined in consultation with the Ministry of Environment, and the Ministry of Agriculture and Food (Appendices G and H). The nutrient content of

sludge should be tested prior to use, so as to determine correct supplementary fertilizer application rates.

- Application:
  - Can be surface spread (dry or liquid) and tilled into the soil surface.
  - Can be injected (liquid) into soil.
  - Sludge should be spread only when the soil is firm enough to carry the equipment (4).
  - Winter spreading of sludge is not permitted on slopes greater than 3% for soils of moderate to slow permeability (4).

5.4.3 Agricultural Lime

- Agricultural lime is a finely ground lime material commonly applied to agricultural lands to adjust soil pH from an acidic to a more neutral pH.
- Application rate: should be determined by sending representative soil samples to a laboratory for pH analysis.
- Application technique: lime can be mixed in with topsoil (and other amendments, if used) prior to spreading or can be broadcast over soil and incorporated prior to seeding (5).
- If agricultural lime is not available, your local supplier can recommend an appropriate substitute, based on the laboratory analysis of soil pH.

5.4.4 Fertilizer

- Fertilizer products are added to correct soil nutrient deficiencies.
- Application rate: to be determined annually during the establishment of vegetation, and every other year thereafter, by sending representative soil

samples to a soil testing laboratory for nutrient analysis. The species mix will determine whether a fast release or slow release fertilizer should be used.

- Application techniques: typically broadcasted over soil and incorporated by tillage if necessary. When applied to existing vegetation tillage is not appropriate.

5.5 TILLAGE

- Tillage of the soil is undertaken in an attempt to reduce the bulk density of overly compacted soils, to eliminate developing rill erosion, and/or to incorporate seed and amendments into the soil surface after broadcasting.

- When used to incorporate seeds into the soil, the depth of tillage should be shallow so as not to bury the seeds. Note: Some seeds require surface exposure or minimal soil cover to germinate. Check with seed supplier.

- Caution should be used, since tillage can increase erosion potential on slopes. The direction of travel should be parallel to the toe of the slope (i.e., tillage should be undertaken across the slope, not up and down).

5.6 SEEDING

- Due to habitat differences, the prescribed seed mixture may vary over the site to account for soil conditions, aspect, slope, end use etc. Timing of seed application is critical. The method of application can also vary from broadcasting, to the use of a seed drill, to hydroseeding.

- Seeding Methods:
  i) Broadcasting - The seed bed should be fully prepared, followed immediately by seed broadcasting done by hand or by using a hand powered rotary broadcaster. Broadcasting should be done in two applications, the direction of travel of the second application at right angles to the first to avoid seeding gaps. Half the prescribed seed mix rate should be applied in each pass over. Usually broadcasting is used on

steep or inaccessible slopes and swales, where the use of equipment moving along the contour would be dangerous. If erosion mats are to be used, they should be installed immediately after seeding.

ii) Seed Drill - Where the slope is gentle enough (less than 1V:4H), the use of a seed drill is the most efficient method of applying seed, and allows for fertilizer to be applied at the same time. Drilling at a 90° angle to the water-flow direction traps moving soil at the root line established by the drill (29). If a mulch is to be applied it should follow immediately.

iii) Hydroseeding - The use of hydroseeding allows seeding to take place over an area up to 100 m wide with a single passage of equipment. Hydroseeding has the advantage of allowing fertilizer, lime, and mulches to be applied at the same time as seeding, but is more expensive than using a seed drill. Typically, slopes over 1:3 are hydroseeded.

- Timing - The planting program should be planned and undertaken so as to set out the seeds at the most ideal time of the year to allow them to take advantage of available moisture and growing conditions. The best time is in the spring, as soon as the land is workable without damage. Second best is early fall in climates where seedling establishment can take place before freeze-up. The seed supplier can provide cut-off dates appropriate to the seed mix being used. The start-up and cut-off dates used by the Ministry of Transportation for regions in Ontario are provided in Table 2.

Seeding in the summer is not recommended due to the hot and dry conditions which are not favourable to seedling establishment. However, some research provides examples of nurse crop and permanent species establishment during the summer months, using warm season grasses which can germinate and establish under drier and hotter conditions (41).

TABLE 2: M.T.C. START-UP AND CUT-OFF DATES

Seeding and mulching should not be carried out after cut-off dates indicated.

OPERATION	SOUTHWESTERN ONTARIO	SOUTHERN ONTARIO	NORTHERN ONTARIO
Seeding and Mulching	That area of Ontario south of a line joining Grand Bend and Clarkson	That area of Ontario between the northern and southern boundaries of Southwestern Ontario and Northern Ontario respectively	That area of Ontario north of a line joining Waubaushene, Severn Bridge, Bancroft and Ottawa
Seeding with Hydraulic Mulches	Spring start-up to June 14 AND August 16 to September 30	Spring start-up to June 14 AND August 1 to September 30	Spring start-up to June 14 AND August 1 to August 31
Seeding with Straw Mulch	Spring start-up to November 15	Spring start-up to October 31	Spring start-up to October 15
Final Seeding cut-off date	November 15	October 31	October 15

Taken from: Turf Establishment, January 1986. Landscape Operations Unit, Maintenance Branch, Ministry of Transportation and Communications.

6.0 IMPLEMENTATION

6.1 PLANNING AND DESIGN STAGES

In an ideal situation, consideration for the revegetation program will begin during the planning and design stages of the landfill site:

- the slope length angle will be designed to be 1V:4H or less;
- the slope length will be interrupted with terraces or benches;
- the low permeability cap will have a sufficient soil and topsoil cover to protect the cap from freeze-thaw, drying, and root penetration (23, 30);
- the topsoil cover depth will be determined (minimum 20 cm), and the quantity of topsoil known;
- advance planning will be done to handle large quantities of water coming off the site during high rainfall (29);
- the end use of the site will be determined;
- vehicular movement will be planned so the routes avoid channelizing of storm water and melt water (29);
- the sequence of operations will be established so as to take advantage of available on-site topsoil (stripped or stockpiled).

6.2 REVEGETATION PROGRAM

The management of a revegetation program should work toward optimizing the time of seeding, since this provides the best chance of establishing a vegetative cover. Therefore, all preliminary work must be planned, identified and phased, as far in advance as possible, so as to provide the prepared seedbed at the correct seeding time.

Step 1 - Site Analysis

The site to be revegetated should be thoroughly examined, using the 'Problem Evaluation Check Sheet', and the 'Key to Identification of Potential Sources of Problems', both provided in this manual (Sections 3.1 and 3.2).

Step 2 - Soil Testing

Representative soil samples should be collected from as many locations as site conditions warrant. It is better to have too many samples than too few. Samples should be identified as to their location on the site, and submitted for analysis. It is important to know: nutrient status (phosphorus, potassium, nitrogen), soil pH, bulk density, and texture. If any soil samples were taken where contamination is suspected (gas, leachate, heavy metals, etc.) arrangements should be made to test for these as well.

Step 3 - Determining Special Needs

With the information collected in Steps 1 and 2, the special needs of the site will be apparent:

- need for soil amendments (fertilizer, lime, organic matter, etc.)
- toxicity problems (gas or leachate, heavy metals, etc.)
- stability risks (steep slopes, erosion, settling, etc.)
- the presence of acceptable vegetation

Step 4 - Determining Vegetative Cover Requirements

Based on the intended end use of the site, together with the growing conditions (soil, climate, slopes, etc.) and required amendments, the special mixes should be determined in consultation with the seed supplier(s).

Step 5 - Undertaking the Work

The available resources need to be evaluated: Slope rebuilding, hauling topsoil, fertilizing, seeding, etc. perhaps cannot be done with existing landfill equipment and

staff. Equipment purchases may be necessary. Contractors may be required for all or part of the work. Lead time will be required to organize personnel, to order materials, fertilizers and seed, and to arrange contracts. In order to meet the planting deadline, a list of preparation requirements from Steps 3 and 4 should be made, and the time required to schedule each. Working backward from the planting deadline, the schedule will indicate when work should be undertaken.

7.0 FOLLOW-UP

The achievement of successful revegetation does not end with planting the seed. Although intended to be low maintenance and self-sustaining, the vegetative cover may require upfront management. The course of nature could soon begin to conflict with the objectives of the landfill cover if unacceptable species begin to invade the site.

The revegetation program may involve a considerable expenditure of funds and resources. In order to obtain the maximum return from this expense, a commitment to follow-up care is essential. The following sections provide appropriate recommendations.

7.1 VEGETATION MONITORING

As soon as germination begins, the operator should inspect the entire site to observe whether any gaps occurred in the seeding. These could be hand-seeded immediately. As well, inspections after rain events should reveal erosion problems, which should be repaired immediately.

The operator, with the assistance of the seed supplier, should become familiar with the species in the mixes, and where they were used, so that the desirable species can be recognized with certainty.

As the seeded vegetation becomes established, the regular inspections will reveal if weed species are establishing, whether gas kills are occurring, and whether remedial

planting will be required in the next planting season. The use of the 'Problem Evaluation Check Sheet' (Section 3.1) and the 'Key to Problem Identification' (Section 3.2) will assist in focusing on the required actions.

7.2 SOILS MONITORING

The fertility of the soil may vary from year to year, due to the nutritional demands of the vegetative cover, the leaching of nutrients by precipitation, the effects of soil amendments over time, and the natural 'weathering' of the soil. In order to maintain adequate soil nutrition, annual soil testing is recommended (early spring) until the cover is established (i.e., 2 to 3 years), and then, every other year thereafter. Based on test results, the recommended fertilizer can be applied as required in the spring providing the conditions are appropriate.

7.3 MAINTENANCE PROGRAM

The maintenance of the vegetative cover can be expected to be more demanding in the first few years, until satisfactorily established.

The maintenance program should include:

- specialized cutting requirements of the nurse crop (to stimulate root growth and limit shading of permanent species) as per instructions of seed supplier. This may involve manual cutting on slopes too steep or inaccessible for equipment;
- two to three cuttings of the established vegetation per year (as per suppliers' details);
- fertilizing, as determined by soil testing, (see Section 4.3.5);
- repairs resulting from gas/leachate, settling and erosion problems;
- reseeding, where vegetation is thin, and where repairs have been undertaken;

- control of weed species, including trees and shrubs, which may threaten the integrity of the cap with tap roots (30) and compete with the cover species for nutrients and moisture;

- eliminating burrowing animals which can facilitate erosion and/or penetration of the cap by precipitation (30); and

- regular, thorough examinations to detect potential problems from landfill settling, cap collapses, gas/leachate problems, drought and/or erosion.

7.4 RECORD KEEPING

In addition to the records required for landfilling, records should be kept for all activities related to preparing and undertaking the revegetation program. This includes notes taken during site inspections, completed check sheets (Section 3.1), photographs, etc. These will prove to be invaluable sources of information regarding successful species, fertilization, trouble spots, costs, and solutions as landfill staff change over time. The following list may be used to set up a notebook to keep the records, with additional headings, as appropriate:

a) **Cap Material** - source, date when placed, how thick, weather, staff.

b) **Topsoil Cover** - source, date when stockpiled, date when placed, how thick, weather, staff.

c) **Preparation** - what done, what equipment, staff, dates, weather, products used.

d) **Soil Testing: Yearly** - site location of test materials, testing laboratory, tests done, date, results, staff.

e) **Fertilizer Products: Yearly** - source of materials, what product used, where applied, date, weather, comments.

f) **Seed Mix** - species used, where mix used, suppliers, day of planting, preparation of land, weather, success rate, comments.

g) **Erosion, Gas or Leachate** - where, cause, how big, corrective measures, weather, date, success.

h) **Mulch and Erosion Mats** - product name, supplier, where used, date, success, follow-up.

i) **Reseeding** - location, reason, seed mix, date, weather, success.

j) **Nurse Crop: for each cut** - date, weather, comments.

k) **Permanent Species: yearly, for each cut** - date, weather, comments.

l) **Herbicide/Pesticide** - where used, reason, application rate, product, supplier, staff, date, weather, success, precautions, comments.

m) Other points of interest.

7.5 PROFESSIONAL ASSISTANCE

- Landfill operators should not hesitate to make enquiries to the suppliers of seed, fertilizer, erosion mats, equipment, etc., if the use or application is uncertain or unsuccessful.

- The local representative from the Ministry of Agriculture and Food (OMAF) can be a source of invaluable information regarding seeding, fertilizing, soil testing, etc. (Appendix F). In non-agricultural areas of Northern Ontario, contact the district office of the Ministry of Northern Development and Mines.

- The MOE is responsible for all approvals and inspections regarding landfill operation in Ontario. They should be contacted with any concerns relating to planning, operating, closing and/or monitoring.

8.0 SUMMARY

Erosion of landfill sites, particularly the side slopes, is an ongoing problem in Ontario. If not rectified, erosion leads to aesthetic and operational concerns, as well as failure to comply with current regulations.

Once slopes are made mechanically stable, the establishment of shallow, fibrous rooted turf is an effective means of controlling erosion. However, the harsh conditions of the landfill site make it difficult to establish a cover.

This manual provides two methods of assessing site characteristics (Section 3.0), with explanations of site factors, why they can be a problem, and how they can be improved (Section 4.0). The manual does not provide cook-book solutions: each landfill site has unique physical characteristics related to it. Rather, this manual provides a means of assessing problems and determining possible causes. Upon this basis, improvements can be planned (Section 5.0) and implemented as required, in order to establish an appropriate vegetative cover (Section 6.0). The key points to include in a maintenance program are provided in Section 7.0. References used in the manual are listed in Section 10.0.

Sources of assistance, materials and information are provided in the appendices of the manual, to facilitate applying the manual to a work program for a particular site.

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Central Region
Muskoka - Haliburton District
Peterborough District
Toronto District
York-Durham District

North East Region
Kenora District
North Bay District
Sault Ste. Marie District
Sudbury District
Timmins District
Thunder Bay District

South East Region
Cornwall District
Kingston District
Ottawa District

South West Region
London District
Owen Sound District
Sarnia District

West Central Region
Cambridge District
Hamilton-Wentworth District
Welland District

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- Cherokee Construction and Disposal, Mr. Alfeo Spudoni

During the study, several staff at Gartner Lee Limited, contributed to its success including:

- Mr. D.S. Osmond
- Mr. T.W. Hilditch
- Ms A.J. Gould
- Ms C. Heseltine
- Mr. C.P. Hughes
- Mr. R.E.J. Leech
- Mr. R.C. Dickin

Manual prepared by:
GARTNER LEE LIMITED

Norman DeFraeye
Landscape Architect

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APPENDICES

APPENDIX A

SAMPLE COMPLETED CHECK SHEET

FIGURE 3: PROBLEM EVALUATION CHECK SHEET

1. Instructions for Use

Locate the problem areas on the landfill and sketch them on a copy of the site plan, an air photo, or on the attached diagram (Fig. 4). Using a check sheet for each problem area, check off the details that apply. Identify the different problem areas on the map as A, B, C, etc. and use the same coding on the check sheet.

2. SITE: A DATE: Oct 17 89
INSPECTOR: Fred M WEATHER: Clear Sunny Cold
Light rain yesterday

3. Pace the distance from the toe to the top of slope, across the problem area. Take big steps, considering that each pace is 1± metre. More details can be found in Section 4.1.

SLOPE LENGTH
Long (150 to 300m)
Medium (60 to 150m) ✓ 146 paces in gulley
Short (30 to 60m)
Very Short (0 to 30m)

Check off correct range.

4. Have an assistant stand on the slope or use a stick about 2m in length which can be stuck into the ground. From a view point about 20 metres away on the same level, estimate the distance from the top of your assistant's head horizontally to the slope, using their height as a unit of measurement. This will give you the Vertical to Horizontal ratio of the slope, ie. one unit of height vertically = two units of height horizontally. Fig.5 shows other ways to measure slope steepness.

SLOPE STEEPNESS

Check off closest range

Vertical		Horizontal	
1	:	1 or Steeper	
1	:	2	✓ I shovel height to 2 est.
1	:	3	
1	:	4 or flatter	

5. On bare ground portions of the slope, look for:

° Upper layer of soil has washed away leaving exposed stones, sticks, debris.

° Surface runoff has cut small channels 0 to 10cm in the cover materials.

° Running water has cut one or more channels deeper than 10cm.

One, two, or three erosion types may be present on the same problem area. Refer to Section 4.2 for more details.

EROSION TYPES

SHEET EROSION:
Whole site*
Limited area*
Absent None on Site A

RILL EROSION:
Whole site*
Limited area* ✓ 2 other than gulley
Absent

GULLY EROSION:
Present* ✓ 146 paces
Absent

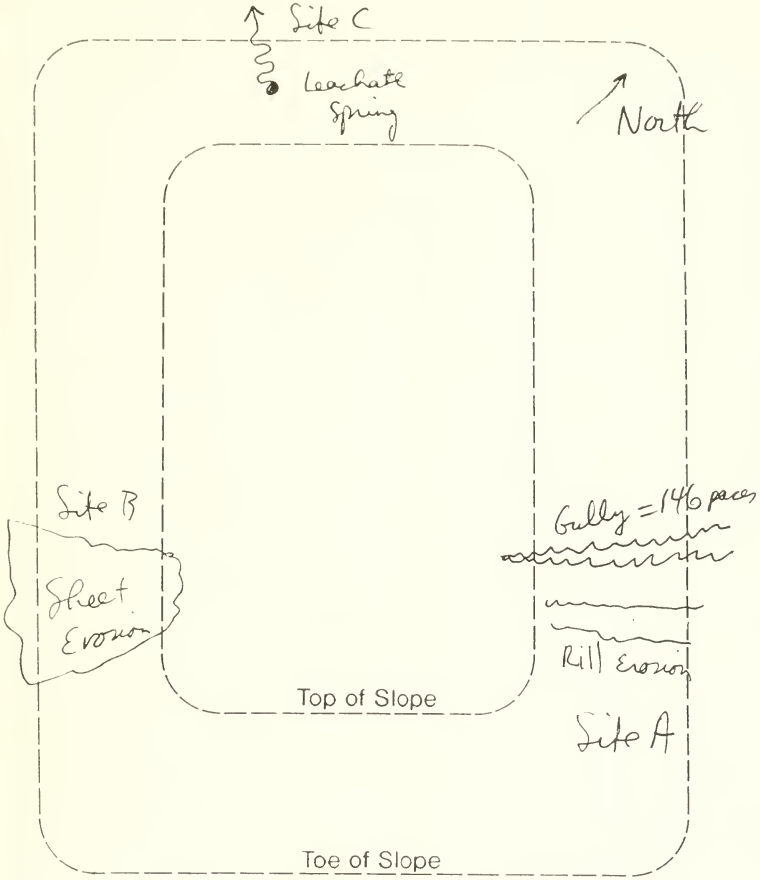
*Be sure to sketch on plan.

Check presence or absence of one or more erosion types, and note details such as length, width and depth.

FIGURE 3: (Cont'd). Site 'A' continued Oct 17/89

6.	Using the soil texture field tests described in Appendix C of the manual, determine the soil texture, or collect small samples in plastic lunch bags and bring them back to analyse when you can refer to the test instructions. Remember to identify where the sample was taken, using the coding for the problem areas. Refer to Section 4.3.3 for further details.	SOIL TEXTURE Sand Silt Clay ✓ in Gully Bottom Loam (topsoil) ✓ on top, about 6" Check or describe appropriate texture
7.	Look for dark soil colour with small bits of decaying leaves and roots. A small sample can be collected and labelled. When you get back, shake up the sample in a jar full of water. If there is organic matter in the sample, it will tend to float on the water in the jar. See also Section 4.3.4.	ORGANIC MATTER Present ✓ some dead stuff in topsoil Absent Not Determined Check presence or absence
8.	Observe whether the surface is smooth, hard, and/or difficult to push a shovel or stick into. This is further described in Section 4.3.1.	COMPACTION Yes (hard) ✓ clay No (softer) Not Determined
9.	The presence of cracks, or soil blowing into drifts, usually indicates dry condition. Refer to section 4.3.6. for description.	LOW SOIL MOISTURE Yes ✓ clay cracked where exposed No Not Determined ~ topsoil - can't tell

Note - will go back to do check sheets on Sites B & C next week.



Inspector Fred M Date Oct 17/89

Weather Clear Sunny cold

REFER TO FIGURE 3 SECTION 1. FOR COMPLETION INSTRUCTIONS

Add any other features : Property Lines . Fences . Water Courses . Treed Areas . Active Fill Areas . Access Points

Sketch Plan For Problem Areas

FIGURE 4

LANDFILL REVEGETATION MANUAL

KEY TO PROBLEM IDENTIFICATION

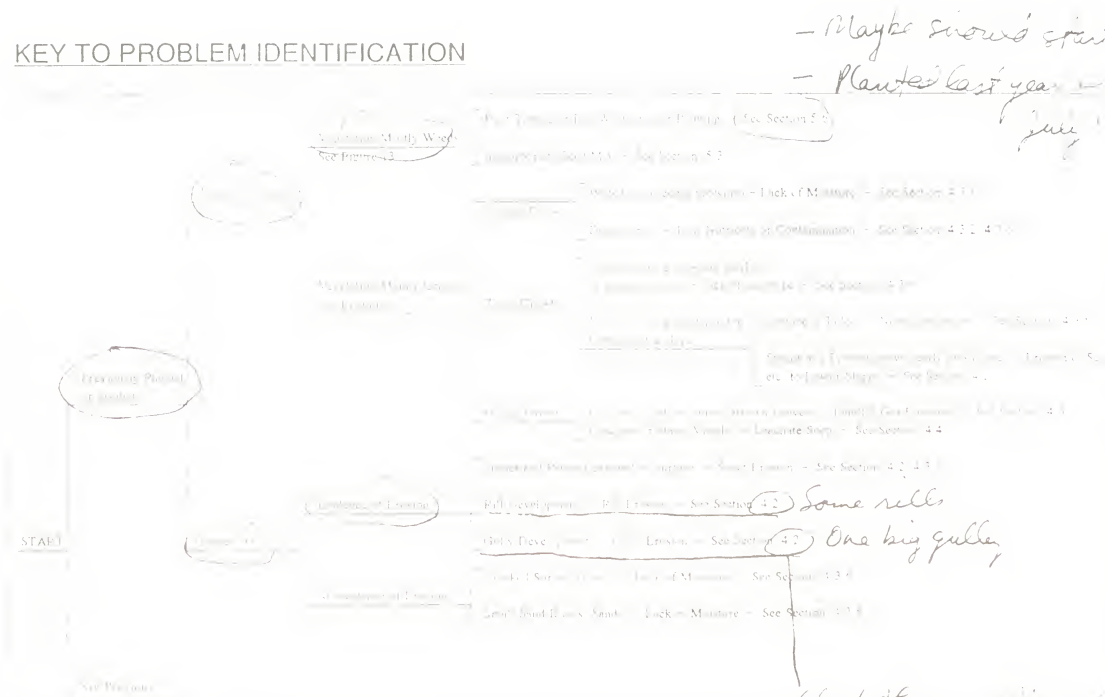


FIGURE 6. KEY TO PROBLEM IDENTIFICATION

APPENDIX B

SOIL TESTING LABORATORIES

APPENDIX B
SOIL TESTING LABORATORIES

Consult with the local OMAF office for a list of testing laboratories, or contact:

Analytical Services Laboratory Department of Land Resource Science Ontario Agricultural College University of Guelph Guelph, Ontario 519-824-4120	Basic analysis includes: phosphorus, potassium, magnesium, pH, and fertilizer requirements (excluding nitrogen). Other tests: particle size, distribution, organic matter/ carbon, bulk density, moisture content.

The soil testing laboratories should be contacted for current test prices and soil sampling kits.

APPENDIX C

SOIL TEXTURE FIELD TESTS

APPENDIX C
SOIL TEXTURE FIELD TESTS

1. Moist Cast Test:
   Moist soil (may be dampened if necessary) is compressed in the clenched hand. The cast is then lightly tossed from hand to hand to assess its binding strength.

Result	Texture
No cast	Sand
Weak cast (allows careful handling)	Silt
Strong cast	Clay

2. Ribbon Test:
   Moist soil is kneaded with the fingers and rolled into a cigarette shape. The soil is then squeezed out between the thumb and forefinger to form the longest, thinnest ribbon possible.

Results	Texture
Unable to ribbon	Sand
Flakes instead of ribbons	Silt
Forms a long, thin ribbon	Clay

3. Feel Test:
   The soil is rubbed between the thumb and forefinger to gain a feel for its coarseness or fineness. The soil is then rubbed in the palm of the hand to dry it and to separate and estimate the amount of individual sand particles. The sand particles are then allowed to fall off the hand and the amount of finer material remaining (silt & clay) is noted. Sand has a grainy feel, silt feels floury while clay feels very smooth.

Results	Texture
Grainy with no floury material	Sand
Very floury	Silt
Smooth	Clay

You may combine terms, i.e., grainy with some floury material is silty sand.

4. Shine Test:

A small amount of slightly damp soil is rolled into a ball and rubbed once or twice against a knife blade or fingernail.

Result	Texture
Unable to form ball	Sand
Able to form ball carefully (dull shine)	Silt
Very shiny	Clay

Caution:

Soil texture should not be determined by the 'taste test', due to the possibility of chemical and/or biological contaminants.

APPENDIX D

WEEDS

APPENDIX D1: NOXIOUS WEEDS

APPENDIX D
D-1: NOXIOUS WEEDS

In Ontario, 23 weeds are classed as noxious under the Weed Control Act (1974). This Act states that "Every person in possession of land shall destroy all noxious weeds thereon".

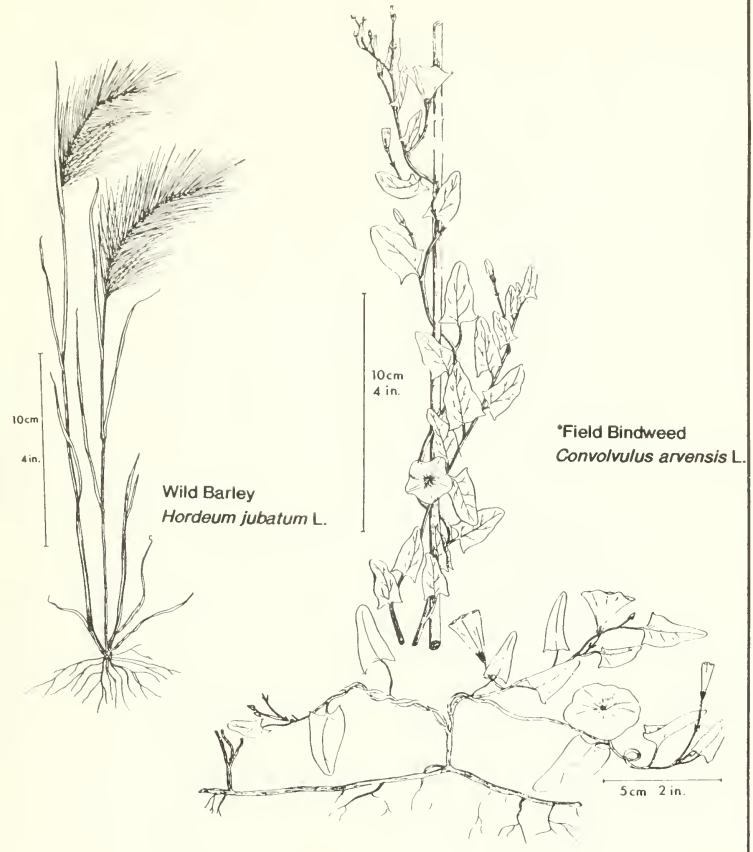
Copies of the Weed Control Act may be obtained from the Ontario Ministry of Agriculture and Food, Toronto, Ontario.

The weeds named below are classified as noxious in Ontario under the Weed Control Act:

Common Name	Scientific Name
Bull thistle	*Cirsium vulgare* (Savi) Tenore
Canada thistle	*Cirsium arvense* (L.) Scop.
Chicory	*Cichorium intybus* L.
Common barberry	*Berberis vulgaris* L.
European buckthorn	*Rhamnus cathartica* L.
Dodder	*Cuscuta* spp.
Field bindweed	*Convolvulus arvensis* L.
Goat's-beard	*Tragopogon* spp.
Johnson grass	*Sorghum halepense* (L.) Pers.
Milkweed	*Asclepias* spp.
Nodding thistle	*Carduus* spp.
Poison-ivy	*Rhus radicans* L.
Ragweed	*Ambrosia* spp.
Russian knapweed	*Centaurea repens* L.
Russian thistle	*Salsola pestifer* A. Nels.,
Scotch thistle	*Onopordum acanthium* L.
Sow-thistle, perennial, annual	*Sonchus* spp.
Cypress spurge	*Euphorbia cyparissias* L.

Leafy spurge	*Euphorbia esula* L.
Tuberous vetchling	*Lathyrus tuberosus* L.
Wild carrot	*Daucus carota* L.
Wild garlic	*Allium vineale* L.
Yellow rocket	*Barbarea* spp.

APPENDIX D2: COMMON LANDFILL WEEDS



Legend

Weeds marked with an asterisk (*) are noxious weeds under the Weed Control Act. Refer to Appendix D-1.

Illustrations taken from 'Ontario Weeds,' from the Ontario Ministry of Agriculture and Food, Publication 505, Agdex 540, 1988.

Illustrations at various scales.

FIGURE

LANDFILL WEEDS

D-2

LANDFILL REVEGETATION MANUAL

Blueweed
Echium vulgare L.

Catnip
Nepeta cataria L.

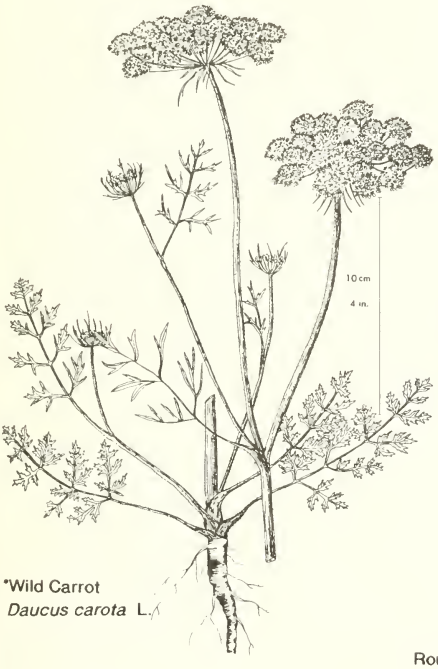
Legend
Weeds marked with an asterisk (*) are noxious weeds under the Weed Control Act. Refer to Appendix D-1.

Illustrations taken from 'Ontario Weeds,' from the Ontario Ministry of Agriculture and Food, Publication 505, Agdex 540, 1988.
Illustrations at various scales

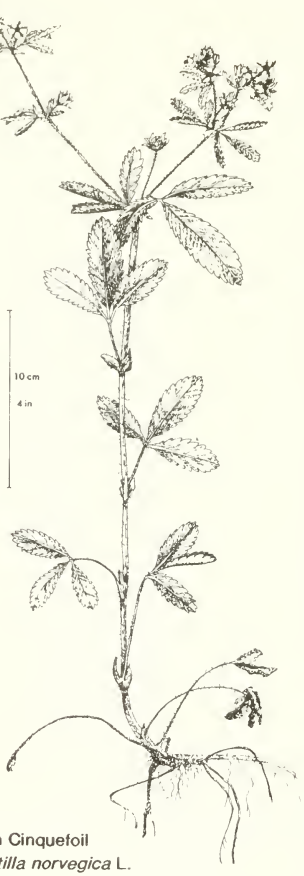
LANDFILL WEEDS

FIGURE D-2

LANDFILL REVEGETATION MANUAL



*Wild Carrot
Daucus carota L.



Rough Cinquefoil
Potentilla norvegica L.

Legend

Weeds marked with an asterisk (*) are noxious weeds under the Weed Control Act. Refer to Appendix D-1.

Illustrations taken from 'Ontario Weeds,' from the Ontario Ministry of Agriculture and Food, Publication 505, Agdex 540, 1988.

Illustrations at various scales.

LANDFILL WEEDS

FIGURE D-2

LANDFILL REVEGETATION MANUAL

*Chicory
Cichorium intybus L.

Green Foxtail
Setaria viridis (L.) Beauv.

Legend

Weeds marked with an asterisk (*) are noxious weeds under the Weed Control Act. Refer to Appendix D-1.

Illustrations taken from 'Ontario Weeds,' from the Ontario Ministry of Agriculture and Food, Publication 505, Agdex 540, 1988.

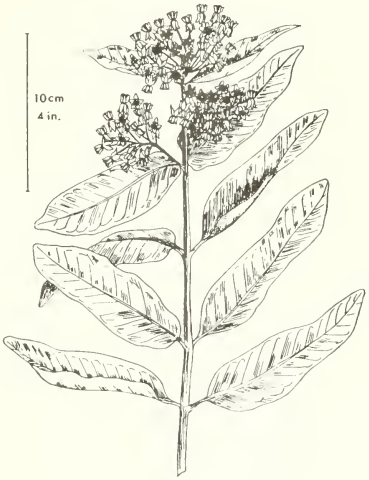
Illustrations at various scales

LANDFILL WEEDS

FIGURE D-2

LANDFILL REVEGETATION MANUAL

Lambsquarters
Chenopodium album L.



*Milkweed
Asclepias syriaca L.

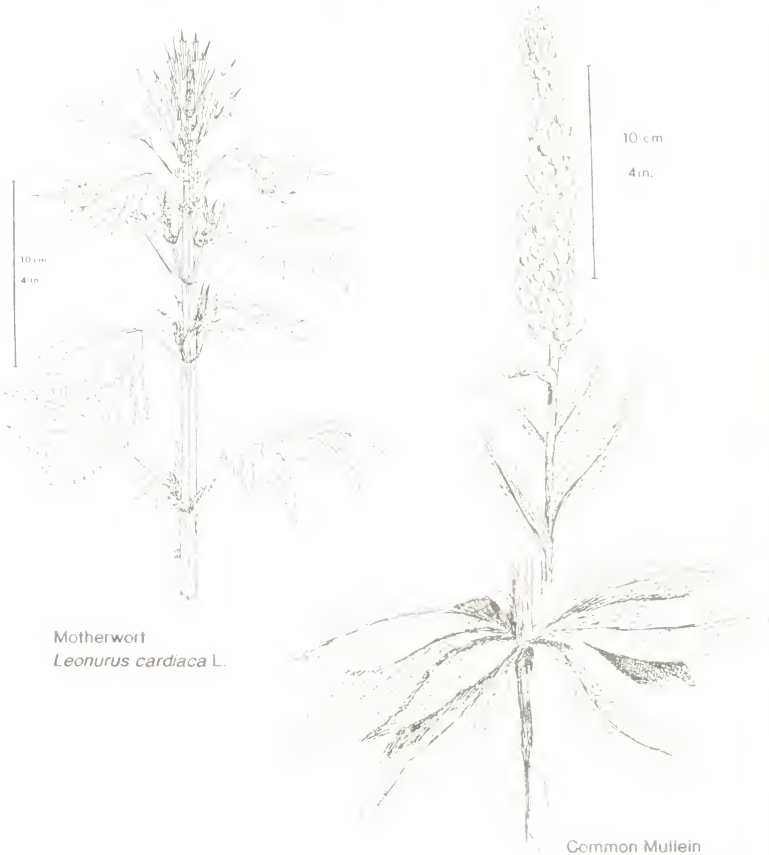
Legend
Weeds marked with an asterisk (*) are noxious weeds under the Weed Control Act. Refer to Appendix D-1.

Illustrations taken from 'Ontario Weeds,' from the Ontario Ministry of Agriculture and Food, Publication 505, Agdex 540, 1988.
Illustrations at various scales.

LANDFILL WEEDS

FIGURE D-2

LANDFILL REVEGETATION MANUAL



Motherwort
Leonurus cardiaca L.

Common Mullein
Verbascum thapsus L.

Legend
Weeds marked with an asterisk (*) are noxious weeds under the Weed Control Act. Refer to Appendix D-1.

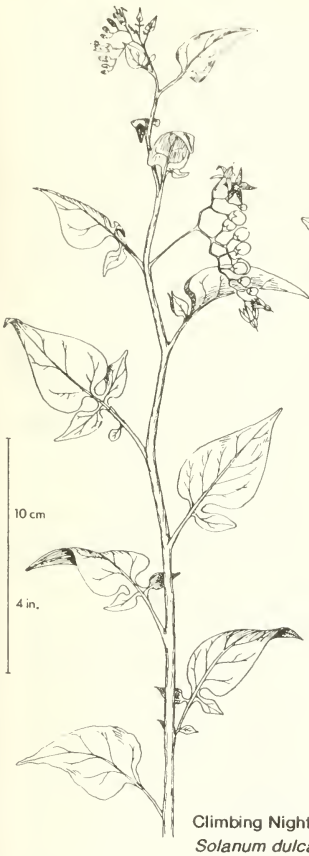
Illustrations taken from 'Ontario Weeds,' from the Ontario Ministry of Agriculture and Food, Publication 505, Agdex 540, 1988

Illustrations at various scales

LANDFILL WEEDS

FIGURE D-2

LANDFILL REVEGETATION MANUAL



Climbing Nightshade
Solanum dulcamara L.

Redroot Pigweed
Amaranthus retroflexus L.

Legend

Weeds marked with an asterisk (*) are noxious weeds under the Weed Control Act. Refer to Appendix D-1.

Illustrations taken from 'Ontario Weeds,' from the Ontario Ministry of Agriculture and Food, Publication 505, Agdex 540, 1988.
Illustrations at various scales.

FIGURE D-2

LANDFILL WEEDS

LANDFILL REVEGETATION MANUAL

Shepherds Purse
Capsella bursa-pastoris (L.) Medic.

*Common Ragweed
Ambrosia artemisiifolia L.

Legend
Weeds marked with an asterisk (*) are noxious weeds under the Weed Control Act. Refer to Appendix D-1

Illustrations taken from 'Ontario Weeds,' from the Ontario Ministry of Agriculture and Food, Publication 505, Agdex 540, 1988
Illustrations at various scales

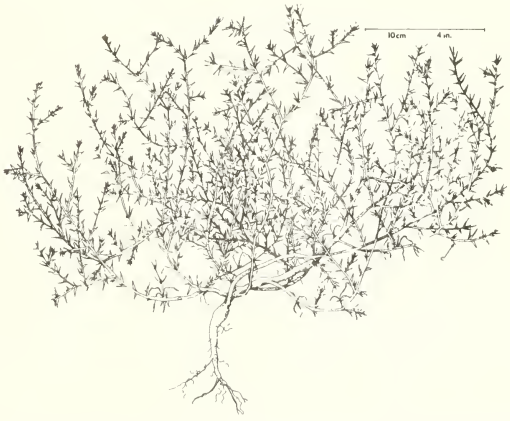
LANDFILL WEEDS

FIGURE D-2

LANDFILL REVEGETATION MANUAL

*Canada Thistle
Cirsium arvense (L.) Scop.

*Russian Thistle
Salsola pestifer A.Nels.



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Illustrations at various scales.

LANDFILL WEEDS

FIGURE D-2

LANDFILL REVEGETATION MANUAL

APPENDIX E

HOW TO LOCATE SUPPLIERS

APPENDIX E

HOW TO LOCATE SUPPLIERS

To find local suppliers of seeds, mulches, fertilizer, and equipment, there are several routes to pursue:

a) Yellow Pages Index
- look under:
  - Agricultural Chemicals
  - Engineers - Environmental
  - Environmental Consultants
  - Erosion Control
  - Farm Equipment
  - Fertilizers
  - Garden and Lawn Equipment and Supplies
  - Landscape Contractors
  - Landscaping Equipment and Supplies
  - Lime
  - Seeds and Bulbs

Not all of these listings may be in your local Yellow Pages, but call the ones that are there. If they cannot supply you with what you are trying to locate, ask them if they can suggest who might be able to provide assistance.

b) Blue Pages Index - Provincial
- look under:
  - Agriculture and Food
  - Natural Resources
  - Transportation

Explain what you are trying to do and ask if any of their special projects or maintenance people could help you locate products/services.

c) Blue Pages Index - Local Municipalities
look under:
Engineering Department
Roads Department
Parks Department

Explain what you are trying to do and ask if they could provide a list of suppliers that they would contact for such products/services.

d) Canadian Land Reclamation Association,
Box 682, Guelph, Ontario N1H 6L3

Explain what you are trying to do and where you are located, and ask if they could provide a local contact for the services or products you want.

APPENDIX F

OMAF OFFICES

APPENDIX F: OMAF OFFICES

Algoma District Office
1496 Wellington St. E.
Sault Ste. Marie P6A 2R1
705-253-1161
Zenith 98750

Brant County Office
207 Greenwich St.
Brantford N3S 2X7
519-759-4190
Zenith 19750

Bruce County Office
Box 1330, 10 Jackson St.
Walkerton N0G 2V0
519-881-3301
Zenith 97920

Carleton Office
26 Thorncliff Pl.
Nepean K2H 6L2
613-828-9167
Zenith 13510

Cochrane (North) District Office
Experimental Farm
Kapuskasing P5N 2X9
705-335-5828
Zenith 43340

Cochrane (South) District Office
Box 608, 4th Ave.
Matheson P0K 1N0
705-273-2509
Zenith 34920

Dufferin County Office
R.R. 4, Mono Plaza, Hwy. 10 N.
Orangeville L9W 2Z1
519-941-3830
Zenith 98750

Dundas County Office
Box 488, 457 Main St.
Winchester K0C 2K0
613-774-2313
Zenith 19750

Durham East Office
234 King St. E.
Bowmanville L1C 1P5
416-623-3348
Zenith 73040

Durham West Office
Box 309, 16 Bascom St.
Uxbridge L0C 1K0
416-852-3328
Zenith 64720

Elgin County Office
594 Talbot St.
St. Thomas N5P 1C7
519-631-4700
1-800-265-4377

Essex County Office
46 Fox St.
Essex N8M 2S2
519-776-7361
Zenith 13510

Frontenac County Office
Box 651, 1055 Princess St.
Kingston K7L 1H3
613-545-4360
Zenith 35050

Glengarry County Office
Box 579, St. George St.
Alexandria K0C 1A0
613-525-1046
Zenith 46710

Grenville County Office
Box 2004, Ont. Gov't. Bldg.
Kemptville K0G 1J0
613-258-8295
Zenith 99200

Grey County Office
181 Toronto St. S.
Markdale N0C 1H0
519-986-2040
1Zenith 16310

Haldimand Office
Box 129, Cayuga St.
Cayuga N0A 1E0
416-772-3381
Zenith 46710

Halton Office
17 Wilson Dr.
Milton L9T 3J7
416-878-2314
Zenith 33440

Hastings County Office
Box 340, 234 North St.
Stirling K0K 3E0
613-395-3393
Zenith 43340

Huron County Office
Box 159, 20 King St.
Clinton N0M 1L0
519-482-3428
Zenith 73040

Kenora District Office
Ontario Govt. Bldg.
Box 3000
Dryden P8N 3B3
807-223-2415
Zenith 46320

Kent County Office
Box 726
435 Grand Ave. W.
Chatham N7M 5L1
519-354-2150
Zenith 33440

Lambton County Office
Box 730, 4238 Petrolia St.
Petrolia N0N 1R0
519-882-0180
Zenith 43350

Lanark County Office
10 Sunset Blvd.
Perth K7H 2Y2
613-267-1063
Zenith 33440

Leeds County Office
Box 635, 44 Parkdale Ave.
Brockville K6V 5V8
613-342-2124
Zenith 46320

Lennox & Addington County Office
41 Dundas St. W.
Napanee K7R 1Z5
613-354-3371
Zenith 18210

Manitoulin District Office
Box 328
Gore Bay P0P 1H0
705-282-2043
Zenith 64720

Middlesex County Office
50 King Street
London N6A 2P2
519-434-6811
1-800 265-4750

Muskoka & Parry Sound District Office
Box 130, 8 Centre St. N
Huntsville P0A 1K0
705-789-8886
Zenith 59650

Niagara (North) Office
Vineland Station L0R 2E0
416-562-4142
Zenith 47710

Niagara (South) Office
574 South Pelham St
Welland L3C 3C6
416-[illegible]
Zenith[illegible]

Nipissing District Office
222 McIntyre St. W
North Bay P1B 2Y8
705-474-3980
Zenith 97920

Norfolk Office
Box 587, Blue Line Rd.
Simcoe N3Y 4N5
519-426-7120
Zenith 38300

Northumberland County Office
Box 820, 95 Dundas St.
Brighton K0K 1H0
613-475-1630
Zenith 34920

Oxford County Office
Box 666, Hwy. 59 N
Woodstock N4S 7Z5
519-537-6621
Zenith 99200

Peel Office
35 Van Kirk Dr., Unit 9
Brampton L7A 1A5
416-451-5474
Zenith 43350

Perth County Office
413 Hibernia St.
Stratford N5A 5W2
519-271-0280
Zenith 35050

Peterborough County Office
55 George St. N.
Peterborough K9J 3G2
705 745-2403
Zenith 16310

Prescott County Office
Box 110, Main St
Plantagenet K0B 1L0
613 673-5115
Zenith 48110

Prince Edward County Office
Box 470, Hwy. 33 W
Picton K0K 2T0
613-476-3224
Zenith 98750

Rainy River District Office
Front St.
Emo P0W 1E0
807 482-2310
Zenith 35050

Renfrew County Office
315 Raglan St. S
Renfrew K7V 1R6
613 432-4841
1 800 267 8816

Russell County Office
666 Rue Notre Dame
Box 540
Embrun K0A 1W0
613-443-3391
Zenith 47710

Simcoe (North) County Office
Box 340, Hwy. 27 S.
Elmvale L0L 1P0
705-322-2231
Zenith 34920

Simcoe (South) County Office
Box 370, 509 Victoria St. E.
Alliston L0M 1A0
705-435-5521
Zenith 43340

Stormont County Office
Box 97,
Avonmore K0C 1C0
613-346-2143
Zenith 38300

Sudbury District Office
1899 LaSalle Blvd
Sudbury P3A 2A3
705 566-1630
Zenith 73040

Thunder Bay District Office
Ont. Govt. Bldg
435 James St. S.
Thunder Bay P7E 6E3
807 475-1651
Zenith 18210

Timiskaming District Office
Box "G", Hwy. 11B N
New Liskeard P0J 1P0
705 647-6701
Zenith 16310

Victoria County Office
322 Kent St. W
Lindsay K9V 2Z9
705-324-6125
Zenith 97920

Waterloo Office
279 Weber St. N.
Waterloo N2J 3H8
519-884-5390
Zenith 46320

Wellington County Office
R.R. 1
Fergus N1M 2W3
519-846-0941
1-800 265-8332

Wentworth County Office
R.R.1, Hwy. 53 E.
Ancaster L9G 3K9
416-527-2095
Zenith 13510

York Office
Newmarket Plaza
Newmarket L3Y 2N1
416-895-4519
Zenith 59650

APPENDIX G

FACT SHEETS AVAILABLE FROM ONTARIO MINISTRY OF AGRICULTURE AND FOOD

APPENDIX G

FACT SHEETS FROM OMAF

The following publications are available from:

Consumer Information Centre
Ministry of Agriculture and Food
801 Bay Street, Main Floor
Toronto, Ontario
M7A 2B2
Tel: (416) 326-3400

a) Fall Fertilization of Turf - R.W. Sheard (39)
In one page the nutrient uptake of turf is described, along with recommendations of when and how to fertilize. To order refer to: Agdex 273/532.

b) How and Where to Use Sewage Sludge in Crop Production
- T.E. Bates, H.C. Lang and J.L. Bourque (4)
This paper discusses the available nitrogen in sludge, its use on mineral soils, application rates, heavy metal contamination, and timing of application. To order refer to Agdex 100/541.

c) Seeding of Erosion Control Projects - A.W. Bos, D. Hilborn and H. Wright (7)
Information is provided describing the use of vegetation to prevent erosion and how and when to seed and apply fertilizer. Some guidance is provided concerning ongoing maintenance. To order refer to Agdex 751.

d) Soil Acidity and Liming - T.E. Bates, T.H. Lane and R.W. Johnston (5)
The importance of pH in soils is described. Application rates and lime quality are discussed with respect to the correction of soil acidity. To order refer to Agdex 534.

APPENDIX H

MINISTRY OF THE ENVIRONMENT REGIONAL OFFICES

APPENDIX H:
MINISTRY OF THE ENVIRONMENT OFFICES

SOUTHWESTERN REGION

London (519 681-3600)
985 Adelaide St. S. N6E 1V3

Windsor (519 254-5129)
250 Windsor Ave. N9A 6V9

Sarnia (519 336-4030)
242A Indian Rd. S. #209 N7T 3W4

Owen Sound (519 371-2901)
1180 20th St. N4K 6H6

Chatham (519 352-5107)
435 Grand Ave. W. N7L 3Z4

WEST CENTRAL REGION

Hamilton (416 521-7640)
119 King St. W. 12th Floor
Box 2112, L8N 3Z9

Cambridge (519 623-2080)
P.O. Box 219, 400 Clyde Rd.
N1R 5W6

Welland (416 735-0431)
637-641 Niagara St. N. L3C 1L9

CENTRAL REGION

Toronto (416 424-3000)
7, Overlea Blvd. 4th Floor
M4H 1A8

Oakville (416 844-5747)
1226 White Oaks Blvd. L6H 2B9

Barrie (705 726-1730)
12 Fairview Rd. L4N 4P3

Gravenhurst (705 687-3408)
Gravenhurst Shopping Centre
R.R. #1 P0C 1G0

Peterborough (705 743-2972)
139 George St. N. K9J 3G6

SOUTHEASTERN REGION

Kingston (613 549-4000)
133 Dalton Ave.,
P.O. Box 820
K7L 4X6

Cornwall (613 933-7402)
408 Pitt St., Box 1479
K6H 1B1

Belleville (613 962-9208)
15 Victoria Ave., K8N 1Z5

Ottawa (613 521-3450)
2378 Holly Lane K1V 7P1

Pembroke (613 732-3643)
Riverside Dr. K8A 6X1

NORTHEASTERN REGION

Sudbury (705 675-4501)
199 Larch St. P3E 5P9

North Bay (705 476-1001)
1500 Fisher St.
Northgate Shopping Centre
P1B 2H3

Sault Ste. Marie (705 949-4640)
445 Albert St. E. P6A 2J9

Parry Sound (705 746-2139)
74 Church St. P2A 1Z1

Timmins (705 264-9474)
83 Algonquin Blvd. W.
P4N 2R4

NORTHWESTERN REGION

Thunder Bay (807 475-1205/1315)
435 James St. S. P7C 5G6

Kenora (670 468-5578)
808 Robertson St. P9N 1X9

APPENDIX I

MOE PUBLICATIONS

APPENDIX I

MOE PUBLICATIONS

PUBLICATIONS

Obtainable from MOE's Communication Branch in Toronto, (416) 323-4321.

- Guidelines for Sewage Sludge Utilization on Agricultural Lands (OMAF, MOE, Ministry of Health)

- MOE Fact Sheet about Sewage Sludge in Agriculture